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General Report of Erosion Conditions on the Colorado River and Tributary Drainages in Colorado 1931

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SAN JUAN RIVER DRAINAGE

The area discussed under this title includes the portion of the San Juan drainage within the San Juan Basin in southern Colorado and northern New Mexico, lying north of the San Juan River and east of Shiprock, New Mexico, together with a relatively small area in the Blanco and Navajo River drainages, both of which empty into the upper San Juan from the east. Below the mouth of the Navajo the course of the San Juan changes from southerly to westerly. The larger streams flowing into the San Juan below this point from the north include the Piedra, Pine, Animas, La Plata, Mancos Rivers, and McElmo Creek. A considerable area south of the San Juan River in New Mexico was not visited in connection with the preparation of this discussion and only a relatively small part of the drainage in Colorado could be examined.

Geology

Volcanic rocks, consisting of various forms of trachyte° and trachytic breccia, occur along the Continental Divide from the headwaters of the Navajo River westward to the Pine River drainage. On the upper Pine River and extending westward rocks of the Archean group and of the Silurion, Denovian, and Carboniferous systems in the form of metamorphic granites, quartzite and a great variety of metamorphic, igneous and sedimentary rocks are found in addition to the trachytes°. The extremely

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°Grouped in the Hayden Report under the term "Trachorheites, see "Ninth Annual Report of the Geological and Geographical Survey for the year 1875," page 93.

rugged area within the Needle Mountains and around Silverton is made up of a great variety of ancient rock formations broken up extensively by faults, folding, and uplifts.

Practically all of the area except the higher mountain region just below the Continental Divide is within a vast area of sedimentary formations, represented principally by rocks of the Cretaceous and Tertiary periods. A few miles north of Durango outcrops are found of the Dakota, Mancos, Mesa Verde, and Wasatch formations. These outcrops appear in the form of irregular belts running east and west in the order (from north to south) named above.

A large area of Mancos shale 25 or 30 miles wide extends north and south across the San Juan River Valley, starting in northwestern New Mexico, it includes Shiprock, continues northward taking in most of the southwestern portion of Colorado, west of the Mesa Verde National Park; thence extending eastward, the belt includes an area to the north of Mesa Verde consisting of a strip of from one to fifteen miles wide, to the Navajo River, following rather closely the line immediately below the abrupt slopes and cliffs which separate the higher from the intermediate altitudes of the basin.

Soil

The sedimentary formations, in which the shales predominate throughout most of this area and especially along the valleys and more rolling uplands, give rise to heavy clay or adobe soils over practically all of this region, below the Engelmann spruce type. In the larger valleys the soil has been built up by deposits derived from the various rock formations. The soil is deep and fertile with considerable amounts of humus and organic material present except on the upper slopes. There

the soil is rather shallow and dry. Generally the soil on the slopes has a sandy loam composition which grades down to a rich deep alluvial loam or clay soil in the bottoms.

The adobe soils, derived largely from the shales, have a high alkaline content. Practically all of the ponderosa pine zone of the San Juan Basin is composed of sedimentary formations in which sandstone and shales predominate, forming soils with a high clay content. The ponderosa pine prefers acid soils and avoids those which are heavily alkaline. The fine texture of these soils and their tendency to become extremely dry and hard on the surface is probably the important limiting factor with regard to forest growth rather than the alkalinity.

Within portions of this area along the lower Piedra and Animas River valleys the Wasatch sandstones have given rise to sandy soils and the gullies take the form of wide sandy-bottomed washes.

Topography and Elevation.

The topography of this region varies greatly and elevations range from about 5,000 to 14,000 feet. On the whole, the topography within the higher elevations is decidedly rough and rugged. Comparatively deep, narrow valleys from which steep high mountain ridges and rimrock mesas rise are characteristic of the area within the National Forests. Because of the ruggedness of the topography, the population is confined chiefly to the ranches along the narrow river canyons and a few isolated mining communities high up in the mountains.

The steepest gradients are found within a belt of 10 to 20 miles in width just below, and parallel to, the Continental Divide. Outside of this belt of rugged topography are lower mountains, foothills, and rolling lands which have sufficiently steep gradients to aggravate the

speed and concentration of run-off which causes serious gullying.

Cover

The higher mountains contain extensive areas of Engelmann spruce, aspen, oak brush, and ponderosa pine cover. However, a large area of land which originally bore an excellent stand of ponderosa pine sawtimber is located outside the National Forest. This has been almost entirely cut over within the last 30 to 40 years. Below the pine zone is an extensive area of foothills, covered with juniper-pinon woodland with sagebrush valleys and hillsides intervening. The lower portion of the San Juan River valley includes a large acreage of rolling lands, broken by many rocky canyons, which support only a sparse vegetative cover of semi-desert type, such as saltbush, sagebrush.

Climate

Summer rains occur in the higher elevations during July and August but the major portion of the precipitation, reaching a total of 25 to 30 inches annually, comes in the form of snow during long, cold winters. The climate of the intermediate elevations of the San Juan Basin is characterized by a short growing season, usually from about June 1 to September 15, with long, comparatively mild winters and with average depths of snow of 24 inches to 36 inches. The lower portion of the San Juan River drainage is within a zone of limited rainfall with a considerably longer growing season. Yearlong grazing is possible.

Erosion Conditions by Specific Areas

Animas River. This stream heads northeast of Silverton in the "American Flats" region, an area of public domain largely above timberline which is used for summer pasture by a large number of sheep, and

flows in a southerly direction, joining the San Juan River at Farmington, New Mexico. Just above Silverton Cement Creek flows into the Animas from the north and just below Silverton is the mouth of Mineral Creek which drains a large area to the west within the San Juan National Forest.

The heaviest washing in the upper regions has taken place in the Animas, northeast of Silverton and a wide flood channel has been washed out in the vicinity of that town (Figure 3). In the upper reaches of the Animas drainage are steep, rocky, mountain-sides with very little vegetation. Run-off is heavy from such areas. Ancient landslides, landslips, and rock streams which are all forms of erosion are to be found in a number of places throughout this section of the San Juan mountains.

Some Engelmann spruce forests occur in the higher mountains north of Silverton but the bulk of the area consists of grassland, bare rock surface or talus slopes. This grassland area extends from Silverton to the American Flats and has been for years very heavily grazed by many bands of sheep. Above Silverton there are old deposits of mill tailings but little of this material is going into the stream now. The water was low and clear at the time of the examination. The closely grazed hills above Silverton and Animas Forks on the Animas River show heavy sheet and gully erosion on the steeper slopes where excessive trampling has taken place and the sod cover is breaking down. Lime Creek, one of the side streams, has about 26,000 acres in the Engelmann spruce type which was burned over in the eighties. This area is not restocking satisfactorily but is supporting a fairly good cover of big mountain bunchgrass, weeks, sedges, and some scattered

aspen. While no serious erosion has taken place on this sub-drainage the creek attains a high water level at times.

The river is confined to a narrow gorge for about 35 miles below Silverton and flood waters are kept within bounds by the canyon walls. The first flood on the Animas, of record, to do serious damage occurred in 1911 when general rains in this region in October resulted in very high water for several days. Severe bank and channel cutting was done at that time. In 1927 other floods occurred and during every spring melting snows have resulted in spring floods, each of which adds to the bank cutting process.

The Animas has cut a wide channel through much of the wider portion of its flood plain above Durango leaving a bed of boulders 500 to 1,000 feet wide with vertical actively caving banks through the center of the valley bottom land. This washing has resulted in the loss of considerable, valuable farm land. This condition extends downstream for a distance of about 15 miles below the point where the river leaves the narrow canyon. (Figure 2.)

The lower part of Hermosa Creek, a tributary of the Animas, has a clean channel. Limited amounts of sheet and gully erosion are occurring on this stream but each is relatively unimportant.

On the slopes above Durango the territory is largely covered with aspen, Engelmann spruce, Douglas fir and grassland types, while below the city the hills are covered with juniper-pinon and the flats with sagebrush, with grama grass, bluestem and wheatgrasses more or less intermingled. The vegetative cover becomes more sparse on the lower portion of the drainage, the precipitation becomes less with the decreasing elevation, and the intensity of grazing use also increases.

The lower part of the Animas River is clouded by mill tailings dumped into the stream in the Silverton locality. The channel shows that high waters have been common, and large amounts of sand and silt have been brought into the San Juan by this river. A number of broad, sandy, flat bottomed washes above Aztec carry large quantities of sand and mud into the Animas following heavy rains. One of these washes is located at Cedar Hill just above the highway bridge. (Figure 1.) There mud is deposited at the mouth of the wash and, as a result, the Animas River is crowded over toward the opposite bank following an ordinary shower. The river gradually washes the deposits downstream so they are noticeable for only relatively short periods following rains. Between Aztec and Durango, mud beaches and sand bars may be found frequently along the river channel.

The excessive flood waters of the Animas River are believed to be the result, partially, of natural conditions - very steep slopes and bare rock surfaces. Excessive grazing and trampling has taken place in the high areas of grassland in the upper Animas drainage and there is evidence of accelerated erosion on the headwaters of this stream.

San Juan River. The San Juan River from Shiprock to near its headwaters was followed asclosely as it could be from existing roads. At Shiprock the volume of water is considerable and the current moves along at a rapid rate. The stream, even at low water, is muddy. There are wide beaches of mud and sand along the channel and the river bottom shows the water to be loaded with sand and silt to a point that it cannot all be carried down stream.

Broad, sandy bottomed washes or vertical walled gullies in the clay soils empty into the river from either side. The soil cover at the lower elevations consists of a sparse cover of grama grass, rabbit brush, and striplex, with juniper and pinon on the hillsides. A rapid increase in the amount of sediment shows up in the river channel as the distance increases from the headwaters. For example, at a point just inside the National Forest boundary a clean channel exists while at Arboles, Farmington and Shiprock the mud deposits show a rapid rate of increase. (Figures 4, 5, 7, 8.)

The Large Canyon joins the San Juan at Blanco, New Mexico. Its channel is a dry wash having a sandy bottom about one-half mile in width. It is reported that in the early days the channel of this wash was less than 50 feet wide. A delta of mud and sand has been built up at the mouth of the Canyon which has crowded the San Juan River against the north bank where it is actively cutting away the agricultural bottomland. (Figure 6.) It is evident that much bottomland has been destroyed by past floods in the San Juan valley.

The channel at Arboles, Colorado is rather narrow but it shows considerable evidence of silting and erosion. Excessive gully and sheet erosion exist on the Piedra River (a tributary flowing into the San Juan just below Arboles) for 18 or 20 miles above its mouth. The lower eight or ten miles of this stream shows excessive erosion in the form of a badly washed channel, mud deposits and considerable bank cutting. (Figure 8.) This portion of this has been heavily grazed for many years by sheep and a seriously overgrazed condition has resulted. This situation is especially bad in the juniper-pinon and sagebrush types. (Figure 37-a.) The upper or canyon portion of the Piedra has a good

vegetative cover and erosion is not serious there.

The San Juan River receives heavy contributions of silt from practically every side stream above Arboles and the water is turbid even during low water. That condition exists as far as Pagosa Springs but the channel above that point is clear and free from excessive silting. Conditions continue to improve as one proceeds upstream. In fact, the entire upper portion of the drainage has an excellent vegetative cover and except for marks of high water along the channel there is no evidence of serious erosion having taken place.

Excessive sheet and gully erosion are found on Montezuma Creek, a tributary joining the San Juan a few miles below Pagosa Springs. This valley of this stream has a deep clay soil supporting a cover of sagebrush, rabbit brush, oak brush, juniper-pinon, and scattered ponderosa pine. The gullying in this creek extends from the mouth to the very head of the drainage. Farms located in the bottom land are in places dissected by a veritable network of deep gullies.

Coyote Park is located just over a minor divide from Montezuma Creek and drains into the Navajo River at Edith, New Mexico. Excessive sheet and gully erosion start at the head of each gulch and the gullies increase in size as one proceeds downstream. The portion of the Coyote Park drainage located within the San Juan National Forest has a better vegetative cover and erosion, while not entirely absent, is not so pronounced. Much of the region is privately owned and patented lands are so intermingled with Government lands within the Forest that much unauthorized grazing has probably occurred. Every gulch apparently has its system of gullies which are actively cutting deeper and wider at an

alarming rate. Serious erosion where the vegetative cover has been badly overgrazed, as exemplified in Montezuma Creek and Coyote Park, is taking place throughout a large area in that vicinity.

Sheep Cabin Creek, which flows into the Little Blanco River within the San Juan National Forest, has been overgrazed for a number of years by cattle and the vegetative cover has been seriously depleted. The soil is a clay derived from Mancos shale and the Dakota formations. It is within the ponderosa pine type with oak brush and sagebrush intermingled. Along the bottoms occur bluegrass, bluestem and grama grass, rabbit brush, trailing daisy, and restem vetch. Seven hundred and fifty head of cattle grazed on this allotment for years. In 1927 the number was reduced to 500 head and plans are under way for further reductions. Active sheet and gully erosion are taking place on this area. The smaller gullies appear at the very top of the ridges and rapidly increase in size until on he main creek deep, actively cutting gullies have been developed. (Figures 10, 11, 12.)

Serious sheet and gully erosion are occurring in the area between Durango and Pagosa Springs and extending southward to the State line. This area is largely privately owned although it includes a considerable acreage of public land. Farming is undertaken where water for irrigation is available. Extensive logging operations were carried on in the pine forests in the vicinity of Pagosa Springs beginning in the nineties and continuing until about 1920. The logging operations took place largely on privately owned lands and the commercial timber on such lands has practically all been cut. Before and after logging the lands have been used for pasturing thousands of sheep. It is

estimated that 500,000 sheep are pastured in the San Juan Basin. Formerly 190,000 sheep were grazed in the San Juan National Forest and the number grazed at present is 150,000. The number of cattle grazed on the Forest also has been reduced, from 28,000to 18,000 head. Use of the lands outside the National Forest for lambing grounds as well as for fall and winter range has resulted in serious depletion of the forage crop. Throughout the area in which the extensive logging occurred and excessive grazing has taken place, there is also an excessive amount of sheet and gully erosion in practically all stages of intensity and activity. (Figure 12-A)

The following notations are representative of the erosion conditions existing on much of the lower country between the Animas and the San Juan rivers as noted in following a route from Durango to Bayfield and Arboles. The principal cover types are sagebrush, juniper-pinon, oak brush and ponderosa pine. Soils are largely clay loams and erode readily. The Florida River channel at the highway crossing is clean and the water is clear. The channel shows former high water stages but very little sediment has been deposited along the stream. The Florida River joins the Animas about 20 miles below the highway and within the lower part of its drainage serious erosion is taking place. The more level valley lands and mesas are farmed and the rougher hills are used for pasture. Long Hollow, a tributary of the Florida River from the east, shows heavy sheet and gully erosion of the clay soil. Similar erosion is taking place on many of the other side drainages with the net result that this stream carries considerable quantities of sediment into the Animas River.

The channel of Pine River above Bayfield is generally in good condition with no serious erosion although flood waters have cut a

rather wide channel along the river from this point southward to its junction with the San Juan. Extensive areas of steep, bare rock surface on Vallecito Creek and upper Pine River have caused rapid run-off which has contributed to high water. Dry Creek is a tributary of Pine River from the west. This creek has an extensive system of gullies through its bottomland and sheet erosion is very much in evidence. East of Pine River practically all of the tributary streams show active heavy gully erosion. Where protection has been given the land against excessive grazing, good stands of grama and other grasses occur in the sagebrush. Spring Creek, one of the eastern tributaries of the Pine River, shows serious gully erosion. This creek is usually dry except following rains. As elsewhere in the region, each bottom has an actively eroding gully and surrounding areas show sheet and gully erosion in the various stages.

The above discussion outlines conditions existing on portions of the San Juan River drainage. The areas referred to are believed to be representative ones but a complete survey of the entire territory has not been attempted.

Summarized, we find the following conditions exist:

1. The San Juan River drainage includes an extensive area of sedimentary geological formations at its intermediate and lower elevations which have generally easily erosible clay soils.

2. The nature of the region is such that its most valuable resources have been ponderosa pine forests and forage. The pine forests have been extensively logged since the railroad was built into this part of the State in the late eighties. As a result the entire stand has been practically destroyed and lumbering as an industry is

today of only minor importance.

Stock raising - both cattle and sheep - was a natural result on account of the large acreage of pasture land available. Unwise and excessive use of the pasture lands has, however, resulted in serious depletion of the forage available. This is one of the older settled portions of the State and the number of stock has so increased with development of the region that serious overgrazing and excessive trampling is taking place.

Fires in former years have destroyed large amounts of timber land in the higher mountain regions. In places nature is restocking those burns with the original species and elsewhere sod has covered the ground and is protecting the slopes against erosion.

Considerable areas of steep, bare-rock surface occur in the more rugged mountainous localities from which run-off may be excessive. This natural condition probably has an important influence on the high water common to some of the mountain streams.

Erosion, both sheet and gully, in its various stages of development is occurring throughout most of the area within the sedimentary geological formations at the lower and intermediate altitudes. Sheet erosion is very active and large amounts of fertile surface soil are being carried down the hillsides and into streams. In the dry valley bottoms gullying is so general that practically every gulch has its series of gullies which are rapidly washing away fertile soils. Gullying and bank cutting in dry watercourses and along streams has reached serious proportions in many places through destroying valuable agricultural soils and producing waste lands.

The excessive sheet and gully erosion now taking place in the

San Juan drainage is the most destructive noted anywhere on the western slope in Colorado. The extent of the eroding areas is larger and the amount of eroded material being carried down the San Juan River is believed to be larger than that of any other Colorado stream emptying into the Colorado River. The seriousness of this condition and its apparent tendency toward increasing its destructiveness presents a problem deserving of careful study with the idea of determining the causes of this condition and of bringing about such remedial measures as may be needed.

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DOLORES RIVER DRAINAGE

The Dolores River drainage includes an area of approximately 4525 square miles. It is bounded on the north and east by the divide formed by the Uncompahgre Plateau and the San Miguel and La Plata Mountains. The divide to the south and southwest is less pronounced. On the west it is more prominent, the La Sal and Blue Mountains being the important physiographic feature in it. The San Miguel River which heads in the high, rugged mountains near Telluride is the largest tributary of the Dolores.

Physiographic Features.

Within the extensive area drained by the Dolores River, elevations vary from about 4000 feet at the mouth of the river to nearly 14000 feet at the headwaters. The region consists of a number of extensive plateau-like areas cut by deep gorges or canyons. Deep canyons are found both on the Dolores and on the San Miguel Rivers. The San Miguel Canyon is 400 feet deep at its head and over 1000 feet deep at the mouth. A similar deep canyon confines the Dolores River to its source for much of the distance from its source to its mouth; for the rest the river flows through deep, narrow valleys. Several broad folds have caused the surface to be somewhat irregular. Near Lone Cone Mountain the country is hilly and mesa-like in places. On the north a series of broad folds, the main axes of which extend northwest and southeast, give rise to several anticlinal and synclinal ridges and valleys between the Dolores and the San Miguel. Paradox Valley occupies

one of these anticlines. South and east of Paradox Valley are three additional basins or valleys nearly paralleling each other. These are Dry Valley, Gypsum Valley, and Disappointment Valley, separated from each other by well defined rocky and broken ridges.

Geology

The rugged San Miguel and La Plat Mountains bordering the southeastern part of the drainage include a considerable area near the head of the San Miguel River capped by volcanic rocks. Some of the highest mountains at the head of the Dolores are also capped by similar eruptive rocks. The area of volcanic rocks, however, is relatively small when compared with the entire drainage. The remainder of the area is largely one of sedimentary formations extending to the La Sal Mountains which are also capped by eruptive rocks. Unaweep Canyon at the north end of the Uncompahgre Plateau and also portions of the western slope of the plateau show some limited areas of metamorphic granite surrounded by a large area of sedimentary rocks.

Of the sedimentary formations Carboniferous rocks appear in the lower Dolores Valley and a narrow strip of the system follows the canyon into the Paradox Valley. Carboniferous rocks again appear at the lower end of Gypsum Valley and on the headwaters of the Dolores. Triassic formations cover a large area of bench land on either side of the Dolores Canyon. Jurassic formations appear in many canyon walls and on benches in the central part of the drainage. Formations of the Cretaceous period occupy the greatest part of the central and southern parts of the area. In this system are the upper and lower Dakota sandstones and Mancos shale. The Mancos-shale area is very extensive and includes a vast area of uplands between the upper Dolores and San Miguel Rivers.

Soil

The sedimentary formations in which shale is so prevalent have given rise to a heavy adobe or clay soil on much of this drainage. Sandstones in the northern part have in places given rise to sandy soils but heavy soils are the rule on practically the entire area. In the mesa or upland regions back from the narrow canyons comparatively wide, filled valleys are found. The soil has been deposited to considerable depths in those valleys with more or less surface rock in evidence. Much of the clay soil derived from the Mancos shale formation lacks fertility and organic matter. Alkali - a common characteristic of soils derived from shale - is also present in places. The ponderosa pine type is confined largely to the soils within the Dakota formation in which it thrives best. This soil has a high percentage of clay but contains considerable sand and more organic matter than the soils derived from the Mancos shale.

Climate

In the higher elevations summer rains occur during July and August and precipitation is largely in the form of snow during the remainder of the year. The precipitation over the entire basin will range from about 10 inches to 50 inches annually, according to the precipitation map accompanying Water Supply Paper 617. Irrigation is necessary for crop production on all areas suitable for farming. Winters are long and cold. The monthly mean maximum temperatures at Telluride range from 75° to 36° F.; the monthly mean minimum temperatures, 42° to 7° F.

At the intermediate elevations the growing season is from about June 1 to September 1 with long cold winters and considerably less annual

precipitation than at the higher elevations. At Telluride, elevation 6750 feet, the average frost-free period is 73 days. In the lower valleys the growing season is correspondingly longer and precipitation falls off to about 10 inches, annually. Snows occur from time to time, but not to such an extent as to make yearlong grazing impracticable in the lower part of the drainage.

Cover

A very large proportion of this unit is covered variously with sagebrush, oak brush, aspen and juniper-pinon types. An extensive area of ponderosa pine occurs adjacent to the upper Dolores Canyon. The more rocky hillsides and the steep valley slopes at the lower elevations are covered with a mixture of juniper and pinon; the mesas, benches, valley bottoms, and lower hillsides are covered with sagebrush. Oak brush is found on slopes which have fairly fertile and moist soils within the ponderosa pine zone. Aspen is found on higher slopes and the Engelmann spruce occurs only in the higher portion of the rugged area near the headwaters of the San Miguel and Dolores.

Erosion conditions by specific areas °

The Dolores was examined at its mouth; again at Unaweep Canyon; at its junction with the San Miguel; in the Paradox Valley; at the road crossing west of Disappointment Creek and at the town of Dolores. The San Miguel was followed from its mouth to Placerville. Other parts of the drainage were also crossed as noted below.

At the mouth of the Dolores River the channel is in a rather narrow canyon. The stream appears to be about 100 feet wide and the

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° An early snowfall prevented the examination of much of this drainage and only a brief account of conditions can be given.

flow is sufficiently rapid to carry the load of sediment on downstream. About eight feet above the river is a narrow terrace supporting a thick cover of willows. The Dolores River and the Colorado were, even at low water, turbid at their junction. On each side of the canyon the vegetative cover is scant; the area has been heavily grazed, and sheet erosion has been excessive.

Unaweep Canyon is an unusual physiographic feature. It extends continuously from the Dolores River at Gateway northeast to the Gunnison River at Whitewater. From a high point about midway between the two rivers water flows in opposite directions, forming on one side West Creek which empties into the Dolores; and on the other side East Creek which empties into the Gunnison. The Indian name, Unaweep, designates it very appropriately as a canyon without a head. This gorge has been cut to a depth of 1000 feet or more into metamorphic granite but sedimentary formations are exposed along the lower portion of West Creek. This creek is nearly 20 miles long and, with the exception of the lower portion, apparently is not being damaged seriously by erosion. However, the lower three miles of this drainage are heavily grazed and considerable erosion is taking place. Many dry washes come in from the north and they have wide channels filled with sand washed in from above. This canyon is grazed only by cattle; but to the north, an area known as Pinon Mesa has been heavily grazed by sheep. It is from this area that the lower part of West Creek is receiving the most silt.

At Gateway the Dolores channel shows evidence of high flood waters and excessive silting. The water was very low - at the time the river was examined in connection with this survey - but muddy, due to the presence of silt picked up from the mud-lined channel (Figures 23-24).

Tailings from the mines near the headwaters have added to the silt load but at present there is little mining activity and it is evident that most of the mud has been washed down from the badly eroding areas tributary to this river.

The San Miguel River flows into the Dolores in a deep narrow canyon some distance above Gateway. The San Miguel contributes a large amount of silt. Paradox Valley - a deep, elongated basin - intersects the Dolores River Valley at right angles a few miles above the mouth of the San Miguel. It is drained from the east by East Paradox Creek and from the west by West Paradox Creek. Through the upper portion of Paradox Valley the Dolores has steep, caving banks about six feet high and fairly well covered with willows, thorn apple and sagebrush. Active caving is in progress along the river banks and the water, even when low, is likely to be rather muddy. Extensive mud and sand deposits occur along the channel and these supply the silt which clouds the water.

The rocky hillsides bordering Parqdox Valley are covered with juniper and pinon. Sagebrush, rabbit brush, and greasewood, intermingled with grama grass and bluestem, constitute the principal vegetation. The entire valley has been heavily grazed. A deep gully follows the bottom along the west side of the valley for its full length and numerous branches enter it from both sides. The eastern portion shows excessive grazing use and has a more barren appearance than the west side. In this part of the valley the cover consists predominantly of sagebrush, rabbit brush, sagebrush, grama grass, and matchweed with Russian thistle on old cultivated areas. Here the valley is filled with red soil from the surrounding sidehills.

The bottom, from the Dolores River to the east end of the valley, has a wide, deep, and recently eroded main gully with vertical side walls actively caving. At the extreme east end Mancos shale overtops the red soil. All side canyons carry deep gullies actively cutting deeper and wider channels although the presence of shale in places has checked further deepening of the channels.

Gypsum Valley parallels Dry Creek Basin (the latter a tributary of the San Miguel), the two being separated by an inticlinal ridge. The upper portion of this valley shows very heavy grazing use and active sheet and gully erosion. The lower end of this valley drains directly into the Dolores River. Between Gypsum Valley and Disappointment Creek is another anticlinal ridge while Disappointment Valley is within a syncline. The soil of the latter is clay and the formations include the Dakota and Mancos. An extensive area of the later formation lies in the upper portion of the valley and excessive erosion there° is reported. The cover in the valley is scrubby sagebrush with juniper and pinon on the hills and ridges. The part of the valley visited shows extensive gullying and this valley is reported to be one of the most heavily eroding areas on any tributary of the Dolores River.

The Dolores River is crossed by the highway west of Disappointment Valley. The canyon at that place is narrow and the river swift. The entire surrounding region shows severe grazing use and excessive sheet and gully erosion are occurring.

Farther upstream the Dolores drains a region largely within the Dakota formation. At the town of Dolores the river has a clean channel, the water is clear and little evidence of excessive erosion is to be seen along the channel.

° Not examined in connection with this survey.

The San Miguel River drains much of the locality to the west of the Uncompahgre Plateau. The river rises in the high mountains in the vicinity of Telluride and soon enters a deep narrow canyon through which it flows to its mouth. Cover types include a large area of juniper-pinon, sagebrush, and oak brush on the west side of Uncompahgre Plateau with some aspen, Douglas fir, and Engelmann spruce on more favorable sites. Slopes are steep, bare ledges are numerous, and the vegetative undercover is very sparse within the juniper-pinon type. Rapid run-off is characteristic. A brief shower during the summer of 1931, in which .10 or .15 inch of rain fell, caused streams of water - red with mud - to come tumbling down the canyon sides. The load of silt soon caused the water in the San Miguel to change to a red color indicating an excessive amount of sediment. At Naturita and below, the river bed has deposits of mud often two or three feet deep. The river at low water - cutting into the mud - is always somewhat muddy. At the foot of the gulches are large deposits of rock and gravel washed down from the cliffs above. At the headwaters of the San Miguel the vegetative cover is satisfactory and little erosion is apparently taking place above Placerville. The heaviest erosion seems to be occurring within the juniper-pinon and sagebrush types in the lower half of the drainage basin. In this portion the surface is poorly protected by the vegetative cover and the grazing use is severe.

South and west of Naturita is Long Draw which drains into the San Miguel River. Its dry channel follows a filled valley for 10 miles or more within an area in the Dakota formation. In the bottom of this valley the sagebrush-greasewood type of vegetation is predominant; the hillsides are covered by the juniper-pinon type. The whole area is

heavily grazed, much of it by sheep, and the understory of vegetation, consisting of grasses and weeds, has been seriously depleted. A deep, vertical-walled gully in which there is much active caving follows the full length of the draw. This gully measured 23 feet in depth and about 50 feet in width at one point.

To the west Dry Creek Basin occupies a synclinal valley in which the Dakota and Mancos formations outcrop. This valley was examined near the upper end. The creek is ordinarily dry or is but a small stream except following rains. Mr. R. E. Meeker (Consulting Irrigation Engineer) says that in 1908 this channel was only a few feet wide and not over five feet deep. By 1925 the lower part of the channel had increased to a width of from 30 to 60 feet and to a depth of from 30 to 40 feet in places. This gully is in a clay soil and has vertical walls. It has a length of about 12 miles and many side gullies empty into it. Similar conditions are to be found in a good many other areas in this region and both sheet and gully erosion in practically all stages of development are very commonplace.

Summarized briefly, the following are important points to be considered in connection with the erosion which is taking place on the Dolores River drainage:

Practically the entire drainage area lies within an extensive series of sedimentary geological formations. The shales within these formations have given rise to clay soils containing more or less sand formed from weathered sandstones. The soil is readily eroded unless held in place by an adequate vegetative cover.

The region is naturally adapted to the grazing of livestock and from the earliest settlements has been important in stock raising.

Heavy grazing use has taken place and it is probable that the original cover of forage was much more abundant than that which is found today. It isevident that many parts of the area are now so overgrazed that serious depletion of the cover has taken place.

Excessive sheet and gully erosion are active on much of the drainage. This condition, from all evidence available, seems to have been growing worse in late years and much recent cutting by gullies can be found. The condition of the lower river channels further indicates that large amounts of sediment are being carried downstream. It is difficult to say how much this erosion may have increased in recent years, but the fact remains that it apparently is growing worse constantly and in many localities has already reached an alarming stage.

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GUNNISON RIVER DRAINAGE

Location

The Gunnison River is the largest tributary in Colorado of the Colorado River and flows into the latter at Grand Junction. It in turn has three important branches (1) the Uncompahgre River which comes in from the south and joins the Gunnison at Delta; (2) the Lake Fork of the Gunnison which joins the Gunnison proper at the upper end of the Black Canyon a short distance below Sapinero; (3) the North Fork which flows into the main river at a point about 15 miles east of Delta. These streams drain an extensive valley, horse-shoe in shape, of about 8020 square miles, bounded by the following physiographic features: Grand Mesa and portions of Huntsman Hills and the Elk Mountains on the north, the Continental Divide on the northeast, east and southeast, the San Juan Mountain and Uncompahgre Plateau on the southwest and west.

Physiography

Elevations along the boundary of the drainage range from about 9,000 to 14,000 feet while the altitude at the mouth of the Gunnison is 4,570 feet. However, the elevation of the greater portion of the region is less than 9,000 feet.

Some of the most rugged portions of the Colorado River drainage are included in the Gunnison River watershed. These areas are in the southern and northeastern parts of the drainage. Generally, however, the basin drained by this river and its tributaries is made up of a series of more or less mesa-like formations through which streams have

eroded deep canyons. In the lower portion of the drainage, however, the canyons widen to broad valleys bordered by steep sloping hillsides. Black Canyon, the most prominent physiographic feature of the region, was formed by the river cutting a channel to a maximum depth of 3,000 feet through a plateau having an altitude of 9,000 feet. The canyon itself is 56 miles long. The plateau consists of gneiss overlaid by sedimentary rock which occurs in nearly horizontal strata aggregating 1,000 to 2,000 feet in depth. The canyon has nearly vertical walls and in places is only as wide as the river at the bottom.

Geology

The central and western portions of the drainage are within a region of extensive sedimentary formations in which rocks of the Jura-Triassic and Cretaceous ages predominate. In Unaweep Canyon and the Black Canyon metamorphic rocks, largely granites, schists or gneisses outcrop. These rocks also appear over a considerable area on the upper portion of the watershed. Much of the higher region has a capping of volcanic rock largely lava and trachyte. The West Elk Mountains and most of the higher areas to the south of the Gunnison and east of Cimarron Creek, as well as the high San Juan mountains, are also covered by rock of this character. Formations of the Carboniferous and Silurian systems occur in several places in the higher mountains at some distance northeast of Gunnison. Glacial drift covers some large areas principally along the river at Gunnison, on Tomichi Creek, and in Taylor Park. Altogether, probably in excess of 60 percent of the total area of the Gunnison River drainage is included within the sedimentary formations, of which the Mancos shale is by far the most common.

Soil

The character of the soil is quite varied because of the rock formations from which it is derived. Roughly, the soils may be separated into three main groups: (1) gravelly sandy loam, more or less rock strewn, and fine sandy or silt loam, formed by the breaking down of the metamorphic rocks such as quartzite and granite, characteristic of rough, stony land at higher elevations; (2) deep fertile soils derived from igeneous rock or lava of which the principal type is the silt loam of upland areas; (3) heavy clay soils mainly formed by the weathering of the shales, very sticky when wet. In the lower valleys clay soils predominate, being derived from the various shale deposits which outcrop extensively in this region. Except in the case of soils of practically pure Mancos-shale there is a considerable amount of humus and varying amounts of surface litter present. Oak brush, aspen and coniferous timber types have the greatest quantities of litter and in such areas little erosion is taking place.

The Mancos-shale soils are largely lacking in organic matter and in many places contain excessive amounts of alkali which tend to limit plant growth.

Climate

There is a wide variation in monthly mean temperatures throughout the basin. At Whitepine, at an elevation of 10,000 feet, the monthly mean maximum temperatures range from 69° F. in summer to 28° F. in winter; at Grand Junction - elevation 4,570 - from 91° to 36°; at Gunnison - elevation 7,680 - from 80° to 24°. The monthly mean minimum temperature at Whitepine vary from 38° in summer to 0° in winter; at Grand Junction, from 64°

to 15°; and at Gunnison from 42° to -9°. The daily range is from about 25° to 40° throughout the year, being from 25° to 30° during the winter and from 30° to 40° during the summer. The maximum recorded temperature was 109° at Delta, the minimum -47° at Gunnison. The average period between killing frosts varies from 29 days at Crested Butte to 184 days at Grand Junction. The mean annual precipitation at Grand Junction based on records covering a 32-year period is 8.30 inches, a 36-year mean at Delta is 7.84 inches. This part of the valley, just above the mouth of the river, has the lowest precipitation. Few records are available for the mountain areas where the greatest precipitation occurs; and estimates of the precipitation based on measured run-off of streams, with allowances for losses through transpiration, evaporation, and percolation, as given in U.S.G.S. Water Supply Paper 617 indicate that the mean annual precipitation varies from 21 inches to 48 inches in the upper portions of the Gunnison basin. A map accompanying this Water Supply Paper shows, by means of lines connecting points of equal precipitation, the computed amounts of precipitation for the entire Colorado River drainage in Colorado.

Cover

A wide variation in the type of cover exists. The lower valleys support only a sparse semidesert cover of shadscale, greasewood, saltbush, and sagebrush. Sagebrush also occupies extensive areas of rolling uplands and reaches elevations in excess of 10,000 feet. Juniper-pinon and oak brush types occupy the hillsides at intermediate elevations. Ponderosa pine, aspen, Douglas fir, lodgepole pine, Engelmann spruce, and bunchgrass constitute the remaining major types of cover. All of the above types contain varying amounts of grasses, weeds, and herbaceous plants, forming an undercover within the type.

Grazing

On page 345 of Dr. F. V. Hayden's report for 1876 he states: "An excellent summer range and as yet almost untouched is found on the plateau and in the valleys on both sides of the Gunnison from Cimarron Creek to the mouth of the Tomichi and thevalleys of the Gunnison River, Tomichi and Ohio Creeks and East River with the hills bordering their valleys. In this ar:a the grass is luxuriant and abundant and water is plentiful....."

"The Uncompahgre valley is of little value for grazing. Except in the river bottoms grass is very scarce. In the southern part of the valley in what is known as Uncompahgre Park there are a few square miles of excellent pasture. A narrow strip along the western edge of the valley also contains some grass. The lower part of this valley, known as the Gunnison and Grand River valleys, shows a gradation from bad to worse. There is little grass in either part and that little is so scattered that the cattle would grow poor in searching for it."

The above observations were made at a time prior to general settlement. White settlers were first allowed to take up land in this region in 1881. Practically all of the drainage except irrigated lands is used for grazing of livestock. By following the general practice of moving from the lower to higher ranges in summer and back in the fall, yearlong grazing is possible. Summer ranges are mostly within the eastern portion in National Forests. The cattle grazed are owned by local ranchers. Many sheep are summered on the higher ranges and wintered on the semidesert ranges in the lower valley. Some herds are fed on ranches but most of the sheep are trailed to winter ranges in

Utah. As a result of the excessive grazing use serious depletion in the vegetative cover has taken place throughout much of the lower and intermediate portions of the region.

Erosion Conditions by Specific Areas

Gunnison River. The Gunnison River flows through a narrow canyon for much of its course between Grand Junction and Delta, a distance of about 45 miles. The river has cut deeply into the Dakota formation most of the way. South of the river, the land surface rises rather uniformly to thetop of Uncompahgre Plateau. This plateau is made up of sandstones of the Dakota and Jura-Triassic formations. North of the river canyon, a strip of Mancos shale averaging nearly 10miles in width, follows up the valley to the mouth of the Uncompahgre River where it divides and continues in one direction up the Uncompahgre Valley in a strip about 12 miles wide for a distance of 50 miles; and extends in another direction up the Gunnison Valley about 15 miles, thence up the North Fork of the Gunnison to a point a few miles above Paonia. This extensive area of Mancos-shale soil has a naturally sparse vegetative cover. In addition practically all of it is so heavily overgrazed that the normal cover has become seriously depleted. Excessive sheet and gully erosion are everywhere in evidence and large amounts of sediment are carried into the river. As a result, rather large tracts within the Mancos-shale formation present a barren appearance with little or no surface vegetation and the opportunity for erosion is much greater than on areas possessing a good vegetative cover. (Figure 25.) The lower part of the Gunnison Valley includes some badly eroding pebble-stream hills which support a very sparse cover of atriplex vegetation. (Figures 76-77.) Although this part of the

drainage is within a zone of limited rainfall, it is not an uncommon event for moderately heavy rains to cause floods to sweep across the semibarren clay surface, cutting deep gullies and carrying large amounts of the most fertile surface soil into the rivers. (Figure 26.)

At the mouth of Unaweep Canyon the Gunnison River is now constantly muddy although the channel has cleared itself of sediment at this point. (Figure 78.) The early settlers hauled drinking water from the river at that point and it was normally clear at that time. East Creek in Unaweep Canyon is about 20 miles long.* Its upper end is within an area of metamorphic granites. The vegetative cover is good at the upper end and little erosion is in evidence. Within the sandstone formation, at the lower end of the canyon, however, vegetation is very sparse, for that locality has been heavily grazed and excessive gullying and sheet erosion are taking place. In the lower part of the canyon an active gully has developed, having vertical sides 12 to 15 feet high and a channel 50 to 100 feet wide which is typical of many of the other tributaries emptying into the lower Gunnison. (Figure 27.)

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*Unaweep Canyon is an unusual physiographic feature. It extends continuously from the Dolores River at Gateway northeast to the Gunnison River at Whitewater. From a point about midway between the two rivers the water flows in opposite directions forming on one side, West Creek which empties into the Dolores; and on the other side, East Creek which empties into the Gunnison. The Indian name, Unaweep, designates it very appropriately as a canyon without a head.

Between the mouth of the North Fork of the Gunnison and the twon of Sapinero, the Gunnison flows through the Black Canyon. The drainage to the south of this canyon below the mouth of Cimarron Creek is very limited but from the north a larger area of public domain, private and National Forest land between Black Mesa and the river, drains into the canyon. Much of this is within the oak brush and juniper-pinon types at the lower elevations with aspen, bunchgrass, and Engelmann spruce types on the higher parts of the mesa. Heavy grazing by sheep has taken place for a number of years and both the public domain and private lands have been so seriously overgrazed that the undercover of weeds and grasses has been seriously depleted. Some areas used by cattle also show a depleted vegetative cover as a result of heavy grazing use. Such use is heaviest near the ranches where the stock is owned. Excessive sheet and gully erosion are evident in many parts of this area particularly where the greatest depletion in the vegetative cover has occurred.

U. S. Highway Number 50 crosses from the Uncompahgre River Valley to the Gunnison proper on the Cerro Summit divide. This point marks the south end of a stock driveway along which many bands of sheep are trailed each spring and fall in going to and from the summer ranges. The driveway follows the west slope of the Black Canyon to its lower end, thence on the north side of the Gunnison River to Grand Junction. Along the entire route the vegetation has been reduced almost to the point of extermination.

Excessive grazing use has occurred from the top of Cerro Summit eastward within the Cimarron Creek drainage (tributary to the Gunnison). Sagebrush and oak brush are the types showing most serious depletion. Gullying starts at the top of the divide and a network of actively eroding

gullies covers the basin. (Figure 85.) Excessive sheet and gully erosion are occurring on all but a few areas which have been fenced and have a good cover of sodded grasses. (Figures 86-89) Cimmarron Creek also shows a seriously depleted vegetative cover at the lower end of the valley and is carrying a heavy load of silt into the Gunnison. A 12-ounce bottle of water taken on August 15 from this creek while it was very muddy following a rain earlier in the day showed after settling 1-1/8 inches of silt in a seven-inch column of water. One of the more recent large landslides of which there is a record for this region occurred on Cimmarron Creek in 1886. This slide is fully described in Professional Paper 67 United States Geological Survey. Other minor slides have occurred in many parts of the area which result in the surface run-off carrying considerable quantities of silt.

The condition of the Gunnison River channel at Iola is very good. It is bordered by rounded pebbles and boulders and vegetation grows well down toward the edge of the water. A maximum range of water stages at that point appears to be about five feet. (Figure 90.)

The area north of the Gunnison River between the Black Canyon and thetown of Gunnison is a rocky sagebrush area which has been grazed so excessively that little is left on the ground except the sagebrush. Sheet and gully erosion are serious throughout all the region bordering the river, and side streams have been carrying large amounts of sediment into it. However, farther back from the river erosion is much less serious on account of the more complete vegetative cover found there.

The town of Gunnison is located near the center of an area 15 or 20 miles across where sagebrush is the major cover type and where the annual rainfall is about 10 inches. Some portions of this area are used by sheep while others are grazed by cattle. The areas nearest the ranches show heaviest use and most serious depletion of the cover.

In the vicinity of Lost Canyon, several miles northeast of Gunnison, the increasing loss of stock from low larkspur has resulted in discontinuing grazing in that region after June 1 of each year. However, early spring and fall grazing generally take place. In every gulch there is an actively eroding gully and the effect of sheet erosion is shown by the hummocks on which the vegetation occurs. The light rainfall materially decreases the possibility of erosion there.

Aspen, Douglas fir, Engelmann spruce, and lodgepole pine form a good cover over much of the higher areas near the headwaters of the Gunnison. Extensive stands of sagebrush grow in parks up to elevations of nearly 10,000 feet. Taylor Park at the head of the drainage is typical of the sagebrush type at the high elevations. Along the creek bottom the soil is alluvial though glacial drift covers extensive areas in the park. Willows and sedges grow along the creeks. Low sagebrush with a good sod undercover of small fescue and ring muhlenbergia occupies the several terraces above the river to the edge of the steeper hillsides surrounding the valley. These hillsides have an excellent cover of Engelmann spruce and lodgepole pine and show practically no erosion.

The Enterprise Mine power plant near the west end of Taylor Park allows waste water to escape from the top of the pressure pipe line 360 feet above the foot of a steep timbered slope. This overflow has cut a

"gash" averaging 15 to 20 feet deep and about 50 feet wide down the slope for a distance of 800 or 900 feet. The surface was originally covered by a dense stand of young lodgepole pine timber. Coarser material in the wash has been deposited at the foot of the slope and only the finer material reaches the river. This occurs whenever water overflows the top of the penstock. Except for this apparently avoidable man-caused erosion, the Taylor River region is suffering but very little from such damage.

Ohio Creek Valley, one ofthe tributaries of the upper Gunnison, includes a considerable area within the sagebrush type showing effects of heavy grazing. Several localities have been excessively grazed by sheep and the forage cover seriously depleted. The sagebrush type on the Slate Creek drainage also shows heavy grazing use, together with considerable sheet and minor gully erosion.

Briefly, the most active erosion within the drainage of the main Gunnison River is taking place within the semidenuded Mancos-shale soils on the lower areas. In many places the sagebrush type has a deficient undercover and is eroding severely. The pinon-juniper and oak brush types also show much active erosion. The upper portion of the area - largely within the aspen, lodgepole pine and Engelmann spruce types - extending to timberline, show very little active erosion.

Uncompahgre River. The Uncompahgre Valley has a total drainage of approximately 1,110 square miles, lying mostly to the south and east of Delta. The Uncompahgre River at its junction with the Gunnison does not indicate excessive erosion above but its narrow channel has caused the sediment brought down to be carried on downstream. The valley,

except for a relatively narrow alluvial deposit along the river, lies in a wide strip of Mancos-shale which continues upstream fifty miles above Delta. On the west side of the river the land rises at a gradual rate of about 150 feet per mile to the top of the Uncompahgre Plateau, which is within the boundaries of the Uncompahgre National Forest. Farm lands border the river and on the eastern slope of the plateau we find in ascending order sagebrush, juniper-pinon, oak brush, ponderosa pine, aspen, and Engelmann spruce types in more or less regular zones. Cattle and sheep grass in the region between the National Forest and the river valley. Excessive grazing use with its trailing and trampling has taken place. The geological formations between the Mancos shale of the valley proper and the plateau to the west are the Dakota and the Jura-Triassic sandstones and shales. The soil is sandy in places but it is mostly clay with considerable surface rock. There is a very thin under-cover of grass and herbaceous plants within the sagebrush and juniper-pinon types. Sheet and gully erosion occur throughout all of the lower areas. Old roads have been badly eroded. The thin soil has been washed away exposing considerable areas of bare rock and the extent of such areas is increasing. The usual accumulation of needles and litter is absent throughout most of the juniper-pinon type. The National Forest boundary follows closely above the juniper-pinon belt and a better vegetative cover exists within the forest. Throughout the oak brush, ponderosa pine, aspen, and Engelmann spruce types the vegetative cover is very good and erosion is little in evidence. Some heavily used salt grounds on the plateau show the effects of excessive trailing and trampling.

Stock trails to salt grounds have in some cases started minor gully erosion. Numerous canyons extend from the plateau in a northeasterly direction and all show the effect of heavy erosion throughout the lower areas. At the north end of the Uncompahgre Plateau, outside of the National Forest boundary, the vegetation shows heavy grazing use and serious depletion in places. Erosion has become very much in evidence and gullies increase in frequency and in size toward the valley. On the east side of the Uncompahgre Valley there is an extensive area of clay soil within the Mancos shale formation which has a very light vegetative cover and which is eroding badly in many places. (Figures 82-83) This land is partially under the reclamation project but many places are now abandoned which at one time were farmed. The soil contains some alkali and its natural vegetation does not indicate much fertility. This applies especially to the soil which has been derived from pure Mancos shale. Peach Valley on the east side of the Uncompahgre Basin shows probably the worst conditions of any part of the valley. The soil there is a heavy clay. The bottomland has a sparse cover of sagebrush, rabbit brush and greasewood with some grama grass and bluestem, while the upper slopes have very little vegetative cover. The lower part of Peach Valley has a gully which in places is 30 to 40 feet deep and 100 yards wide with vertical walls which are actively caving. Large amounts of soil are carried downstream by every heavy rain. Severe erosion is taking place within these shale areas even up to their upper limits. (Figures 28-29.)

Above Ridgeway the canyon of the river narrows and a rough mountainous area of steep slopes with much bare rock surface is exposed. Run-off is excessive after hard rains and floods have filled the stream

channels with rock and debris. (Figures 30 and 31.) The vegetative cover here has not been depleted by grazing or activities of man but apparently it is in as good condition as can be expected. Natural conditions are most favorable for the heavy and rapid run-off which has carried considerable loose rock and soil into the canyons. As a result the lower part of practically every gulch emptying into the canyon is filled with rock, gravel, and debris.

Lake Fork of Gunnison. Lake Fork of the Gunnison includes within its lower drainage a large area of clay soil occupied by the sagebrush, juniper-pinon, ponderosa pine, Douglas fir, and Engelmann spruce types. (Figures 91-92.) The greater portion of this drainage is private land and public domain. Grazing use has been very severe. The sagebrush type shows perhaps the heaviest grazing of any type. It has little if any undercover of weeds or grasses in many places. In the vicinity of Powderhorn postoffice depletion of the herbaceous undercover is especially severe. In that locality there is a noticeably large increase in the amount of sheet and gully erosion. Lower slopes have suffered severely. Portions of roads in slight drainage depressions have been washed full of debris and other portions of this sagebrush area show varying degrees of sheet and gully erosion.

Cebolla Creek, from about two miles above Powderhorn to its source, is a clear mountain stream having an excellent forest cover on its upper slopes with well-sodded grasslands in the creek bottom lands and shows no erosion. Many old and some new beaver dams exist in the channel of the lower part of the creek. (Figures 79-80.)

West of Powderhorn along the road to Lake City the grazing use

has been heavy and the vegetation has been materially reduced as a result. On practically all of the lower slopes excessive sheet and gully erosion are taking place. Heavy washes occurred in 1931 and during the two previous years which brought down large quantities of fine and coarse material. The heavy material has been collecting at the foot of the steeper slopes and only the finer soil goes into the river. The railroad which follows the Lake Fork to Lake City has suffered heavily because of material washed down on the track. The highway has also been damaged in a number of places. A ranch at Gateview postoffice was badly damaged by high water from Indian Creek - one of the side gullies - two years ago. That flood brought down a large amount of silt and other debris for the first time since this ranch was established. Every side gulch draining into Lake Fork below Lake City shows a deep gully and at its lower end varying amounts of debris.

Lake San Cristobal, two miles above Lake City, is formed by an extensive old mud flow which came down Slumgullion Gulch from an elevation 2,600 feet above its present location in the mouth of the gulch. The flow - which is six miles long - after daming Lake Fork turned and followed down the valley three-fourths of a mile. (Figure 32.) This lake is an effective check for eroding material from lands above it and a steady deposit of material is crowding into the lake at its upper end.

At the mouth of Slumgullion Creek a delta extends well out into the lake. The region above the lake is very rough and broken. High waters carry great quantities of rock and gravel into the more level

valleys. The streets of Sherman, an old mining camp, after having stood many years unaffected by floods, have been filled by such material within the past two years to a depth of from one to three feet.

The San Juan Mountains at the headwaters of the San Juan, Lake Fork, Uncompahgre and Dolores Rivers within the Telluride, Rico, Silverton and Ouray topographic-map quadrangles, published by the United States Geological Survey, have nearly 100 landslides, including rockstreams which are of sufficient size and importance to be shown on the geologic maps. They represent a total of over 60 square miles or over six percent of the area of the four quadrangles. United States Geological Survey Professional Paper "Landslides in the San Juan Mountains, Colorado" discusses these in detail.

An example of timberline erosion exists in the "American Flats" region at the headwaters of the Lake Fork drainage. A total of approximately 180,000 acres of high timberline country is located between Silverton, Ouray and Lake City, practically all of it being public domain. Possibly one-half of the area above timberline is barren rock surface, the remainder covered with timberline grasses, sedges and weeds well adapted to sheep grazing. It is estimated that 45,000 sheep have been crowded into the American Flats during each of the past ten years or about twice the number the available range can support. Feed had become so scarce by August 7 in 1931 that some of the bands were leaving for other range. Stands of willows have been almost completely killed out by excessive grazing. Trampling in some places has also resulted in the breaking down of the sod cover. Intermittent minor gullying occurs near the tops of the ridges, and farther downstream considerable

sheet and gully erosion is in evidence. (Figures 33 and 34.)

The entire south slope of Engineer Mountain is badly cut up by many active gullies. These start near the top of the mountain and increase rapidly in width and depth. Widening of the gullies is caused in places by the nearness of the bedrock to the surface. The thin soil on practically the whole south side of Engineer Mountain is being washed down hill. Much of the coarser debris is checked at the foot of the steep slope and finer material goes downstream. The most serious example of timberline erosion seen in 1931 was taking place on American Flats and in that vicinity.

Henson Creek, a tributary of the Lake Fork, drains a large part of American Flats. On the upper portion of this creek there is considerable bank-cutting and evidence of serious erosion. Recent rains have carried quantities of rock and soil into the river channel. Portions of the intermediate drainage have a good cover of Engelmann spruce, aspen, and brush but large amounts of sediment have been carried downstream from the less protected slopes. A small power-project reservoir is located several miles above the mouth of Henson Creek which had become well filled with silt. Opening the headgates and draining off the water has partially cleaned out the mud leaving evidence of the original depth of the silt deposit in a series of terraces. (Figure 35.)

The heavy erosion taking place on the lower part of the Lake Fork drainage, together with the continuation of that on the grassland above timberline, places this area well toward the head of the list in amount of active erosion on the upper branches of the Gunnison River. The nature of the cover and soil types are such that under normal conditions

of use little erosion should result. However, the natural steepness of slopes and the large proportion of exposed, bare-rock surface tend to increase the amount of run-off and makes the region especially subject to serious erosion when natural conditions are disturbed as indicated.

North Fork of Gunnison. The North Fork of the Gunnison River has a total drainage basin of approximately 933 square miles. Except for a relatively small area of farm lands in the lower portions of the valley, it is rather narrow and largely unsuited for uses other than grazing. However, coal mining is an important industry in the valley.

A large area of actively eroding uplands within the Mancos-shale formation borders the farm lands in the lower portion of the valley. The hillsides are covered with juniper-pinon type while sagebrush, greasewood, saltbush, and shadscale represent the principal plants growing in the bottoms and valleys. The region between Paonia and Crawford may be taken as representative. Much of it is practically a "badlands" area (Figure 36) in which numerous gullies and excessive sheet erosion are in evidence everywhere. Very active gullies have been cut to a depth of 30 feet and to a width of 75 feet or more on the lower part of Cottonwood Creek. (Figure 37.) The vertical walls cave off following each rain and a large quantity of the eroded soil is carried into the North Fork of the Gunnison River. The naturally sparse cover of vegetative growth has been severely overgrazed until there is practically no undercover of weeds, grasses and other herbaceous plants remaining in the brush type. Conditions here are similar to those prevailing on a large area which extends for many miles along the north side of the North Fork of the Gunnison River valley down to its outlet. This

extensive Nancos shale area is apparently eroding to a greater extent than any other part of the North Fork drainage.

The river valley above Paonia is narrow. Slopes on the north side are covered by the juniper-pinon type and oak brush. South of the river oak brush is the principal cover type but at the higher altitudes it gives way to aspen and Engelmann spruce. Sedimentary formations of the Cretaceous age prevail over most of this area. The lower slopes show an especially badly depleted forage cover as a result of heavy grazing use. Consequently, rains frequently cause large quantities of mud and debris to be washed down the steep rocky slopes onto the highway and railroad. Each gulch shows a gully cut down through the thin rocky soil to bedrock. In the vicinity of Somerset these conditions were especially noticeable.

Muddy Creek joins the North Fork some 10 miles above Somerset. The lower part of this drainage has been grazed heavily and minor gully and extensive sheet erosion are taking place. However, in the upper portion of this minor watershed the cover of aspen and coniferous timber and bunch grass is adequate to prevent excessive erosion. The upper part of the Muddy flows through clay soils and some steep clay slopes border the stream. These slide into the creek from time to time causing the water to become exceedingly muddy. Following a rain on the night prior to the examination made in 1931, a head of very muddy water was flowing downstream. However, the portion of the stream a mile below was clear for the mud-laden water had not yet reached that point.

The bottom lands in the North Fork Valley, for some distance above the mouth of Muddy Creek, show exceedingly heavy grazing use by sheep.

The vegetation has been badly depleted and there is abundant evidence of active sheet and minor gully erosion. Upon entering the National Forest farther upstream, however, a more complete vegetative cover prevails and no appreciable erosion is occurring. Similarly very little erosion is taking place in the mountains between the North Fork of the Gunnison and Crested Butte, an area covered by stands of oak brush, aspen, Engelmann spruce, and by mountain bunch-grass parks, much of which is moderately grazed by stock.

General.

There is, in the aggregate, a very large acreage of severely eroding land within the drainage of the Gunnison River and its three principal tributaries. As a result large amounts of silt are being contributed to the Colorado River. It is evident that the greatest account of erosion is taking place within the clay soils at the lower and intermediate elevations. There the vegetative cover is naturally very sparse. Also, the original, natural cover has been seriously depleted as a result of excessive and improper grazing use within the sagebrush, juniper-pinon and oak brush types. The areas which are most deficient in cover, either naturally or as a result of heavy grazing use, invariably show the greatest amount of erosion.

The major portion of the eroding area is within a vast region of sedimentary formations, principally those of the Cretaceous period. Of these formations, Mancos shale is the most extensive. Roughly it is estimated that 1,500 square miles of the Gunnison River drainage consists of Mancos shale located on the lower slopes and valleys.

The excessive erosion taking place at timberline on the American

Flats is an outstanding example of erosion at high altitudes and indicates that such areas are not immune from damage when subjected to conditions which destroy the vegetative cover and break down the protecting sod.

The higher elevations, which include the commercial timber types, and which also coincide with the zones of greatest annual precipitation, have an adequate and little-distrubed vegetative cover and normally show very little erosion.

There are very few localities which show any tendency toward natural recovery from erosion, once it has become started. In fact, it appears characteristic for erosion to constantly become more serious with the passage of time. While apparently throughout the areas gullies showing serious erosion are continually increasing in size and numbers no effort is being made so far as known toward checking erosive action.

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YAMPA RIVER DRAINAGE

The Yampa River, known locally as Bear River, rises on the east side of the Flat Tops in the northeastern portion of the White River. The Yampa River flows northeast, emerging from the mountains a few miles above the town of Yampa and continuing north - for most of the course through a broad fertile valley - as far as Steamboat Springs below which it turns sharply to the sest, continuing in this direction to its confluence with Green River just east of the Colorado-Utah line. The main tributaries of the upper Yampa River are Oak Creek, on the west, and Morrison Creek, on the east. Of the numerous tributaries draining the Park Range to the northeast Elk River, emptying into the Yampa below Steamboat Springs, is the largest. Below this are Elk Head and Fortification Creeks draining from the north and the Williams Fork River from the south. At Lily, about 30 miles above the mouth of the Yampa River, the Little Snake River flows in from the northeast. This is the largest tributary of the Yampa and drains a valley which extends west from the Continental Divide for about 60 miles along the Colorado--Wyoming line, parallel with the Yampa Valley, and then continues southwest for about 50 miles to the junction of the Little Snake and the Yampa. The following discussion is based upon an examination of the portion of the Yampa River Valley extending from the town of Yampa downstream for a distance of 150 miles to Cross Mountain (known also as Yampa Peak and Juniper Mountain) which is south of Maybell; and upon an examination of

the portion of the Little Snake River extending from its souce downstream a distance of 80 miles. In general the portions of these drainages indicate are from 30 miles to 50 miles wide; they are located west of the Continental Divide in Routt and Moffatt Counties, Colorado, and in the southwest portion of Carbon County, Wyoming.

Physiographic Features

The elevations of these drainages vary from about 5,800 feet to a maximum of about 12,000 feet. The Little Snake and Yampa Rivers have fairly uniform gradients throughout their full length and the valley proper, in each case, is rather narrow. An extensive area of rolling hills covered with sagebrush lies between the rivers from their junction as far east as Fortification Creek. East of this creek, high mountains rise abruptly and continue eastward to the Continental Divide or Park Range. South of the Yampa River the region is rough, broken and, in general, higher elevations are encountered as one proceeds to the east. The divide between the Yampa and White Rivers is located from about five to twenty-five miles south of the former, and the distance increases toward the east until the headwaters are approached. Throughout the entire area the gradients of the drainage slopes are sufficient to favor serious gullying and other forms of erosion if natural conditions are disturbed.

Geology

The Continental Divide and the spur known as the Gore Range forming the eastern boundary of this drainage - also the eastern end of the Yampa-Little Snake River Divide - are largely composed of metamorphic rocks including granites, quartzites, gneisses and schists with areas of volcanic rock in the Elk Head Mountains and in the vicinity of the Rabbit

Ears. Similar rock is also reported to be on scattered high points surrounding the headwaters of Yampa River. West of the area of metamorphic rocks, which extends both north and south along the Continental Divide and Gore Range to the east of Steamboat Springs, is an extensive area of sedimentary formations of the Jura-Triassic, Cretaceous and Tertiary systems. The greater portion of the drainage described is within this sedimentary area. An extensive area of Carboniferous and Silurian rocks is located west of the junction of the Yampa and the Little Snake and extends westward across the Green River Valley. In places the strata - originally horizontal - are disturbed or crushed by folding or faulting. Red beds occur in the vicinity of Mount Zerkel and Hahns Peak. Mancos shale covers a large part of the Hahn's Peak basin. California and Slater Parks (the latter on the Little Snake River Drainage) are largely within the Lewis shale and Laramie formations of the Tertiary age, cut in places by volcanic dykes. The Yampa River Valley and the dry farming area to the north and west are also largely within the Laramie and Lewis shale formations.

Soil

The character of the soil is quite varied because of the rock formations from which it is derived. Roughly, the soils may be separated into three main groups: (1) gravelly sandy loam, more or less rock strewn, and fine sandy or silt loam, formed by the breaking down of the metamorphic rocks such as quartzite and granite, characteristic of rough, stony land at higher elevations; (2) deep fertile soils drived from igeneous rock or lava of which the principal type is the silt loam of upland areas; (3) heavy clay soils mainly formed by the weathering of the shales, very sticky when wet. Soils of this type are found in

Hahns Peak Basin, California Park, the valley of the North Fork of Elk Head Creek, Wheeler Basin, and in other localities along Elk and Yampa Rivers. In the lower valleys clay soils predominate, being derived from the various shale deposits which outcrop extensively in this region. All the soils have considerable humus content and varying amounts of litter are present. Oak brush, aspen and coniferous timber types have the greatest quantities of litter and in such areas little erosion is taking place.

Climate

The average annual precipitation in the mountainous region is relatively high. Since 1902, the average has been about 25 inches at Steamboat Springs, at an elevation of 6,701 feet. At Yampa the average is somewhat less. West of Steamboat Springs the precipitation gradually becomes less until semidesert conditions prevail in the western portion of the area. In the timbered portions of the mountains snows commonly reach a depth of from four to eight feet between December 15 and April 15.

Annual mean temperatures are low; the winters are long and cold; snow lies on the ground for long periods. Hay is the principal crop and these valleys comprise an important stock-raising region.

Cover

The principal types of cover include: (1) timberland - Engelmann spruce, lodgepole pine, and Douglas fir forests - occupying the higher elevations; (2) woodland, composed chiefly of aspen which is generally located between the coniferous timber and brush types; (3) Brush land, usually below the aspen belt, consisting of oak brush, service berry, chdke cherry, ceanothus, and buck brush with other shrubs more or less

represented; (4) sagebrush, usually at lower elevations and covering extensive areas of rolling foothills. Records of pioneer explorers often mentioned the presence of extensive areas of sagebrush in this region.

Since settlement by the white man, fires have burned over large areas of timberland. The most extensive burns occurred in 1879. Coniferous forests, aspen, oak brush, and herbaceous growth have long since become established on the areas burned over in the early days with the result that little, if any, erosion is occurring on old burns.

In early times extensive herds of cattle were pastured on the excellent ranges throughout the drainage. Overgrazing took place, followed by serious depletion of the forage. Cattle raising later became less profitable and the numbers were greatly reduced. During the past ten ortwelve years sheep have been pastured on much of the area and where this use has not been regulated further depletion of the forage cover has taken place.

On a considerable area between the Yampa and Little Snake Rivers north and west of Craig, the land was homesteaded and dry farming attempted several years ago. This attempt failed and most of those settlers have moved. Much of the land outside the National Forests is in private ownership, large areas having been taken up under the grazing homestead act. There is, however, considerable public domain scattered throughout this region, especially in Moffat County where practically one-half of the total area is listed as open to homestead entry.

Early Records of Conditions

This general region was covered by the Geological Survey parties

working under Dr. F. V. Hayden during the years, 1873-1876. The report published as a result of this field work makes brief reference to the existing conditions; the following excerpts are quoted from the volume covering the year 1876:

Page 8, referring to the territory between the White and Yampa Rivers the report says, "These drainage channels all show marks of an abundant and strong flow of water and of great and rapid denudation of the surface that is drained by them during the wet season of the year."

Page 14, "Like White River the Yampa in its upper portion is a cold trout stream its bed being paved nearly all the way from its source to its mouth with smoothly worn drift pebbles."

Page 374, referring to the Yampa River drainage Hayden says, "The rainfall that occurred several times during our sojourn in this region was violent in the extreme but short in duration. The total absence of a well connected sod permitted the water to run off suddenly as if poured on a crust of terra cotta.....The water flows off rapidly, gathers in its natural drainage channels, through which it ploughs and digs deeper and deeper into the soft material, each creek, large or small producing thereby a perpendicular deep fissure or small canyon which have been seen in places as much as 60 feet deep with only a width of perhaps 20 feet from rim to rim."

Erosion Conditions

Little Snake River. The headwaters of this stream drop off sharply from the Continental Divide flowing through a ground cover of Engelmann spruce and lodgepole pine timber, aspen, oak brush or sagebrush. Throughout this area there is a satisfactory undercover of weeds, shrubs and grasses with but little evidence of erosion. The stream channel is clean and the

water is clear. A large part of this region was burned over in 1879 and only scattered stands of commercial timber are found in the path of that fire. Wyoming sheep graze the upper part of this watershed which is partly within the Medicine Bow and partly within the Routt National Forests.

Practically all of the valley below the mouth of the South Fork is heavily grazed. A strip from one to three miles wide bordering the river shows the heaviest use. Gullying of the lower portions of side drainages becomes more severe as one goes down the main valley; the vegetative cover becomes more sparse and sheet erosion is also more noticeable. At Baggs, a series of semibarren and seriously eroding clay hills, Tertiary formations, appear and continue down the north side of the river for many miles. These hills extend northward from the river for several miles in places. The river water is turbid at Dixon and many mud beaches border the channel. Bank cutting is common and excessive silting is noted along the river below Baggs. On the south side of the river westward from Baggs where the vegetative cover consists largely of such growth as sagebrush, shadscale, saltbush, prickly pear cactus, the soil is sandy with varying amounts of clay. The area shows severe sheet and gully erosion. Frequent wide, dry, sandy-bottom washes extend to the river and the channel has many sand beaches along its course. Thousands of sheep range on this area in the fall, winter, and spring. Little, if any, regulation of grazing use is in effect and as a result the naturally sparse vegetative cover is in a seriously depleted condition. This situation is typical of practically the entire area lying between the Little Snake River and Yampa River,

west of the highway between Craig, Colorado, and Baggs, Wyoming.

Yampa River. The mountain slopes of the upper Yampa River drainage are covered with heavy stands of coniferous timber, aspen, oak brush and sagebrush in more or less horizontal belts. Native forests have not been cut over extensively. The valley lands and mesas are used principally for hay production and stock raising is the principal industry. Yampa river is in very good condition as far as erosion is concerned from its source to a point about 25 miles below Steamboat Springs. Very little bank cutting is taking place, the channel is clean and the water is clear. After a two days' steady rain on October 20 and 21, 1931, the volume of water in the river materially increased but it was only slightly muddy.

In the vicinity of Hayden and continuing from there downstream, bank cutting occurs with increasing frequency and numerous deposits of mud occur along the river channel. These deposits have resulted from contributions of silt from both sides of the river. The soil on each side of the river is clay though along the lower portions of the river course varying amounts of sand occur. This soil seems to erode easily.

Serious erosion is taking place on the sagebrush lands of the lower and intermediate elevations. Much of it was heavily overgrazed by cattle 20 or 25 years ago but has recovered somewhat from that condition. The region from Hayden north to California Park, a distance of about 28 miles, is typical of much of the area undergoing serious sheet and gully erosion. Apparently the present condition has improved in some localities for many of the gullies have a "healed-over" appearance.

Fortification Creek joins the Yampa River at Craig. That drainage is within an extensive area of Tertiary formations and the soil is easily erosible clay. Heavy loads of silt are being brought down this tributary. This is shown by the fact that 36 hours after a two days' rain had ceased on October 23, 1931, the stream was carrying a full load of mud. A bottle containing a six inch column of the water showed one-half inch of mud after settling. Forest Supervisor Ray Peck who was a Forest Ranger in this locality in 1908-09 states that excessive fall, winter, and spring use by cattle at that time had resulted in this area being badly overgrazed. Severe gullying was then under way.

After the range became seriously depleted the number of stock was necessarily reduced and since that time there has been a gradual improvement in the vegetative cover. Mr. Peck said that 50,000 to 60,000 cattle formerly used the territory between the Yampa and the Little Snake River. Even on the National Forest ranges excessive numbers of stock were pastured in former years. A roundup in 1909 on part of the Forest resulted in a count of about 13,000 cattle where but 5,000 were permitted. The stock grazed consisted largely of steers brought in from Texas. After the supply of feed had become so seriously reduced by excessive use as to make the grazing of steers unprofitable, such shipments were discontinued.

Mr. C. B. Patrick who has lived about 25 miles north of Craig for the past 13 years, is authority for the statement that the vegetative cover is now much improved in quantity over that existing when he came to the region. A deep gully near his hours, now 35 or 40 feet deep, has been cut about six feet deeper during the past 13 years than it was at the time of his arrival. This gully is 100 feet across the top and has

sloping sides but the bottom is still actively eroding. The soft sandstone ledge crossing the gully near its bottom has worn back eight feet in 13 years. In 1925 three rains occurred within a period of two weeks and water attained a depth in this gully of from four to seven feet following each of these storms. In fact, the water in the gully often attains this depth following rains though the head of the watershed is scarcely two miles distant. Patrick stated that considerable material, washed from the upper slopes, is deposited along the lower portion of Fortification Creek and the broad shallow channel seems to bear out that statement.

About one-half mile below the Patrick ranch an actively eroding gully, about 30 feet deep and 75 feet wide, occurs (Figure 13). This has been washed out largely within the past 13 years.

A wagon road was formerly in use across this watercourse but it had to be abandoned about 13 years ago when the excessive erosion started.

The characteristic vegetative cover in the upper part of the Fortification Creek drainage is sagebrush. Within each tributary branch - in which there is a great deal of active erosion (Figures 14 and 15) - a system of gullies has developed. Some barren-shale surfaces have little vegetative cover present and are also actively eroding. (Figure 15-A).

Elk River, which joins the Yampa a few miles below Steamboat Springs, has a clean channel and the water is clear. There is little evidence of erosion on the Elk River drainage and the limited amount that is taking place probably constitutes a normal condition. The sagebrush type is not seriously overgrazed and the oak brush, service berry, choke cherry, ceanothus and other shrubs of the brush-land types

above it provide a litter on the ground surfact that effectively prevents wrosion. The aspen type, and above it the Engelmann spruce and lodgepole pine types, show no erosion. The bottom soils are largely clay derived from the outcropping deposits of shale. The Elk River Valley, from the mouth of the River to Glen Eden and thence to Columbine at the head of Willow Creek, showed little evidence of either sheet or gully erosion. An excellent vegetative cover protects the area.

A number of landslips, some of which are quite large, have occurred in the intermediate and higher elevations between the Yampa and the Little Snake Rivers. These are mostly within the shales and clays of the sedimentary formations and occur most frequently on the steeper slopes. In the vicinity of the Bears Ears Ranger Station on Slide Mountain and on several mountains near the South Fork of Slater Creek, whole sides of the mountains seem to be moving. For example, in the summer of 1920 the aspen on 50 or 60 acres was severely damaged, most of the trees being partially uprooted. Another slide has occurred on Sand Mountain. The run-off from these slides carries large quantities of silt for a rather long period after the disturbance occurs.

Summary

Practically no damage through erosion is taking place in the upper portions of the Yampa River watershed (including the tributaries between Yampa and Hayden) or on the upper part of Little Snake River watershed. An excellent vegetative cover occupies most of the area and while this upper portion receives the greatest annual precipitation of any of the rest of the watershed the surface run-off is not excessive and that which does occur is not causing accelerated erosion. The

lower portions of both the Little Snake and the Yampa Rivers show an appreciable amount of recent erosion activity.

Timber areas destroyed by former fires have largely been restocked or support an adequate cover of vegetation to protect the surface against erosion.

The greater portion of the area as a whole lies within a rolling foothill and broken-plateau area where vegetation has been sparse from the time of the earliest settlers. Unregulated grazing use first by cattle and later by sheep has occurred for many years. During that time the vegetative cover has become seriously depleted and there is keen competition for all the existing pasturage. It iswithin the areas showing greatest vegetative depletion that heavy sheet and gully erosion have been taking place for a number of years. The river channels show increasing evidence of this in the form of silt lined channels.

Hayden, in his report of 1876, refers to the bed of this stream being paved nearly all the way from its source to its mouth with smoothly worn drift pebbles. This condition remains true today for the upper part of the river but for that portion below Craig the bed at the river has the pebble bed largely concealed by a covering of silt and sediment.

In places there are indications of less active erosion than existed at former times but as a general rule the sheet and gully erosion, especially on much of the lower portion of this area, continue to become more serious. This section of western Colorado is not as yet suffering from accelerated erosion to the extent that other areas may be, but the fact remains that excessive erosion is taking place as is evidenced by the

presence of very actively cutting gullies and of silt deposits in the lower streams.

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WHITE RIVER DRAINAGE

White River flows in a westerly direction 25 or 30 miles south of, and practically parallel to the Yampa River. Both are important tributaries of Green River. White River empties into the Green about 60 miles southwest of the mouth of the Yampa and about 35 miles west of the Colorado-Utah line. The drainage area of White River in Colorado has a maximum width of about 50 miles and extends east of the State line approximately 100 miles. The river has its source in Trappers Lake under the escarpment of a table-land known locally as the Flat Tops, the perimeter of which curves, crescent-shaped, around the head of the river. High, broken ridges sloping away from the Flat Tops on both sides of the stream form the divides which separate White River from the Yampa River on the north and from the Colorado River on the south.

Physiographic Features

Portions of the lower drainage area still retain a plateau-like appearance but much of the upland has been deeply cut away by ancient erosion. The originally horizontal strata have been considerably modified by uplift or folding action. Elevations vary from about 5200 feet at the mouth of the river to about 12000 feet on the Flat Tops, called also the White River Plateau. The bottom land bordering White River varies in width but, excepting the wider valley in Powell and Agency Parks it is rather narrow for practically its full length. On each side of this are rolling hills badly broken up by canyons and gulches. The surface is more or less rocky. The river has a uniform gradient.

Geology

Volcanic and metamorphic rocks are exposed in the central part of

the White River Plateau and on some of the higher mountains. Surrounding these are superimposed sedimentary strata of the Carboniferous, Jura-Triassic, Cretaceous and Tertiary ages. Limestones and shales of the Carboniferous age occur in the upper White River basin. A few miles above Meeker Jura-Triassic sandstones outcrop across the valley followed on the west by Cretaceous and Tertiary formations represented by the Dakota sandstones, Mancos shale, Bridger, Wasatach, and Green River stages. Cretaceous formations cover considerable areas in the vicinities of Meeker and Rangely but a much greater area is occupied by the Wasatch and Green River formations of the Tertiary system. Practically all of the Piceance Creek drainage is within the Green River formation except for a strip along its east side which is within the Wasatch. Douglas Creek which is the next largest tributary of the White River in Colorado is almost wholly within the Wasatch formation.

Soil

Clay soils containing an admixture of sand in varying proportions predominate over most of this region. They have been derived largely from the shales and sandstones. The valleys are filled - in many places to considerable depths - with soils containing more or less gravel and disintegrated rock. In the upper portions of the area considerable humus occurs and vegetable litter covers the surface. In contrast to this, the lower rolling hills within the semi-desert portions have but limited amounts of humus and surface litter; sheet erosion has removed much of the fertile top soil.

Climate

Summer rains occur during July and August, but the bulk of the precipitation comes in the form of snow in the higher elevations. The

precipitation at Meeker averages 15.83 inches annually with an average snowfall of 69.7 inches and in the higher places the total annual precipitation is probably in excess of 30 inches. The monthly mean maximum temperatures range from 81.8° to 35.4° F; the mean monthly minimum from 45° to 5.4° F. and the average frost-free period is 90 days. Extremes of temperatures have ranged from 103° to -43°F. The lower portion of the watershed has only a scant precipitation, probably not over 10 inches annually, with only moderate snow, so necessary to pasturing much of the area during the winter season.

Cover

The bottom lands, the lower hillsides in the eastern (upper) portion of the area, and the vast area of rolling, broken country in the western (lower) part of the drainage are largely covered with sagebrush. The juniper-pinon type occupies many of the intermediate rocky slopes and canyons. At similar elevations, where the soil is deeper, extensive areas of oak brush, service berry, currant, and other shrubs cover many slopes. The higher elevations have commercial forests of lodgepole pine, Douglas fir, and Engelmann spruce. Within all these types various characteristic weeds, grasses and other plants occur.

This entire region has been an important one from the standpoint of stock raising since the early settlements, in the eighties. The pioneer settlers found extensive areas supporting an excellent growth of forage plants adjacent to their lands. Since both summer and winter ranges were available and hay was produced on orrigated valley lands, the ranchers were generally prosperous. However, the natural adaptability of the country to stock raising led to the overstocking of the

ranges and, according to statements of those familiar with earlier conditions, greater numbers of stock were raised here formerly. The cause of reduction has been attributed to the reduced quantities of forage available on the range lands. Heavy grazing use in former times has resulted in depletion of the forage to a serious extent and while in places the cover is satisfactory and some recovery has been made, much of the area is so heavily pastured that its carrying capacity is constantly decreasing. Within comparatively recent years sheep have been grazed on portions of this region in increasing numbers and on areas outside of the National Forest only a few places escape heavy grazing use by either cattle or sheep. Along with the increase in numbers of sheep pastured, extensive areas of grazing land have been entered under the grazing-homestead laws and outside of the National Forest practically all the more valuable grazing lands are in private ownership. Extensive areas of public land of very low grazing value, however, remain in the western part of this drainage.

Erosion Conditions by Specific Areas

The White River was followed from Rangely to Trappers Lake, a distance of 100 miles, in which the elevation increases approximately 6800 feet. The soil varies widely from the heavy adobe clay derived from the Mancos shale to fertile sandy loams resulting from a mixture of weathered sandstones and the basaltic lava which caps the plateau region and, which because of its greater resistance to weathering, has preserved it from geologic erosion. Rock formations along the river west of the plateau region are largely sedimentary. Mancos shale outcrops in the vicinity of Meeker and also near Rangely. Dakota sandstone and Jura-Triassic sandstone appear in the intermediate

section, while the Wasatch and Green River formations occupy the lower part of the drainage. All of the soils within the drainage area are readily erosible in the absence of a suitable protective vegetative cover. The vegetative cover gradually improves in density from west to east following generally the increase in precipitation which accompanies the increase in elevation.

There is no appreciable erosion on the headwaters of White River and this condition continues downstream nearly to meeker. An excellent vegetative cover is found throughout the upper valley and on the adjacent hillsides. The river banks are covered with grass or brush to the water's edge. The stream is crystal clear, flows in a boulder-and coarse-gravel-lined channel, and shows no evidence of unusually high water. No bank cutting is indicated and side streams have no eroding gullies.

Conditions begin to change in the vicinity of Meeker. Side streams and dry watercourses from the north side of the valley have washed deep straight-walled gullies through the Mancos shale soil supplying the first heavy contributions of silt to the White River. Similar heavy contributions are added at intervals downstream from this point. Between Meeker and Rangely 30 or more large, active gullies are crossed by the highway in a distance of about 60 miles. In the meandering curves of White River below Meeker (Fig. 16) are beaches of sand and mud which have been formed by sedimentation along the channel. Considerable deposits of silt have been left along the river channel at Rangely (Fig. 17). The river bed at this point is 200 yards wide and the water is constantly cutting new channels through the mud. The water, even when low, is constantly turbid as a result of excessive silt deposits in the river channel. The silt carried down White River is supplied by a number of side streams of which

Douglas Creek is an important one. This stream heads along the high divide between the Colorado and White Rivers in a woodland area of aspen and Douglas fir, supporting a good undercover of weeds and grasses. The extreme head of this drainage shows no serious erosion but about a mile below the divide serious gullying starts and continues to the mouth of the creek where it has cut a gully 150 feet wide and 20 to 25 feet deep (Figures 18 and 19). The channel has in places a terraced bottom indicating additional recent deepening. The vertical walls continue to cave and further widen the gully. Douglas Creek apparently is a heavy contributor of silt and at its mouth a well defined fan has been built up of washed-in material which has crowded the channel of White River northward where it is actively cutting into the bank.

Yellow Creek has a large, active gully at its outlet. The water at the mouth of Piceance Creek is turbid. Silt deposits which have been dropped along its channel indicate that active erosion is occurring in the upper drainage. At the mouth of this important tributary a rather large flat delta or cone of coarser alluvial material has been built up and the stream carries down large amounts of silt. The extreme eastern headwaters of this stream contain old gullies, some well sodded over but others indicating that active gullying is taking place.

Piceance Creek occupies a circular basin about 35 miles in diameter. The Green River formation outcrops over most of the area with a narrow strip of the Wasatch formation on the eastern side. The cover consists of sagebrush and oak brush types with scattered juniper-pinon and aspen woodland. Heavy grazing use has seriously depleted the cover both in the upper and lower portions of this drainage.

Sheep Creek empties into White River from the south about three

miles below Meeker. The valley, 11 miles in length, is practically dry. The bottom is within the sagebrush type while juniper-pinon, and oak brush types predominate on the hillsides. The surrounding area has been heavily pastured for a long time. Sheet and gully erosion are present in active stages over much of this drainage. A gully reaching a maximum depth of 40 feet and a width of 100 feet follows the full length of the valley (Fig. 20). In places the side walls are being actively cut away and caving is excessive while elsewhere the banks are sloping and well covered with sagebrush. This gully seems to be less actively eroding than at some former time but is still in bad condition.

In the region north of White River within a distance of about 33 miles between Elk Springs and Baxter Springs U. S. Highway 40 North crosses 22 large gullies. The soil is clay and the natural vegetative cover is very sparse, consisting of sagebrush and saltbush with a very thin admixture of weeds and grass. Juniper-pinon type covers some of the higher slopes. Many of the gullies have been cut through the Mancos shale clay soil to a depth of 30 feet with widths of from 50 to 300 feet at distances of six to fifteen miles back from this river (Figures 21 and 22).

Heavy sheet and gully erosion is also taking place between Baxter Springs and the White River. The soil is sandy in places and becomes heavier toward the river. To cover is a semi-desert type, very thin, and has been heavily grazed. The dry valley shows a small gully at its head which rapidly increases in size in the seven miles it parallels the road. An area of probably 60 sections of Mancos shale north of Rangely has a very scant cover of saltbush and is cut up by a network of small and large gullies. It is supplying a very large amount of silt to the

White River as a result of the heavy sheet and gully erosion which is taking place over the entire area. The lack of an adequate vegetative cover permits excessive erosion.

In this connection mention may be made of a few references made to White River by Hayden's report of 1876. On page 89 he says: "Even in the dry season the White is constantly muddy owing to the character of the strata through which it and its tributaries find their way."

In speaking of River drifts, consisting of waterworn boulders and sand bars in the alluvial valleys of the White River drainage, he says:

> "In the valleys of the White River drainage the accumulation of this material is simply enormous. It traverses the valleys from one side to the other and is sometimes 40 to 60 feet in thickness. Deep gullies are cut into it by every stream coming from either side a fact which makes traveling very slow."

On page 368 referring to the lower White River he says:

> "Very often the banks are abrupt and had to be cut in order to effect a crossing or to enable us to reach water for our animals or ourselves - - - There are few places along White River that are not lined with bluffs, terraces or high banks most of the time approaching the river margin very closely."

It would appear from these brief extracts of Hayden's report that even in 1876 erosion to a certain extent was taking place in the form of gullying and bank cutting but it is difficult to judge just how extensive or serious that erosion was.

Summed up, within this drainage there is an extensive area of sedimentary geological formations largely sandstones and shales which in weathering down have given rise to soils containing various mixtures of clay and sand. Such soils, when exposed to the action of run-off water, are easily eroded.

The natural vegetative cover in part of the area is very thin, especially in the region of lowest annual precipitation. As the precipitation increases the vegetation forms a more complete cover on the ground. In contrast to the semi-desert type of vegetation in the western portion, there are in the eastern or upper portion of the drainage, slopes covered with spruce forests, aspen, oak brush, and mountain bunch grass.

Since the first settlements grazing of stock on the range lands bordering the valley hay ranches has been the principal industry. Increased demand for range has resulted in overgrazing and in many places the most palatable plants and grasses have been so seriously depleted that at the present time competition for the available forage on the ranges is very keen and damage continues.

Sheet and gully erosion in their various stages of development are common along many of the streams tributary to White River which at its lower end shows the cumulative results of the erosion taking place. It is apparent that the erosion is heaviest on the areas having the poorest vegetative cover. Where the cover is naturally scant and where unwise and heavy grazing use have depleted it, the erosion is uniformly excessive. The present rate of cutting in gullies is apparently greater than in past decades. If the present rate had been continued during several decades previous the amount of material carried into the streams would have left much larger gullies than we now find. Present conditions indicate that an excessive and accelerated rate of erosion is occurring on a considerable portion of the White River drainage.

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Colorado River Above the Gunnison River

Location and Extent.

The Colorado River drainage above the mouth of the Gunnison River of Grand Junction includes an area of approximately 8,910 square miles. It lies between the Roan or Book Plateau, the White River Plateau and the Continental Divide on the north, the Continental Divide on the east and southeast, and the Elk Mountains, Huntsman's Hills and Grand Mesa on the south. The North Fork of the river has its source east of Mount Richthofen, a part of the Continental Divide, which reaches an altitude of about 13,000 feet. The South Fork rises below Buchanan Pass and joins the North Fork on the east side of Middle Park. The river flows southwest through Middle Park where it is joined by several tributaries, among which are the Fraser, Williams Fork, and Blue Rivers from the south and Willow, Troublesome and Muddy Creeks from the north. To the west of Middle Park the Colorado River has cut through the Gore Range of mountains and flows through Gore Canyon. The elevation in this canyon decreases 360 feet in a distance of five miles. This is the greatest fall that occurs in the upper portion of the river below the headwaters. Between Gore Canyon and Glenwood Springs the river flows through several canyons with intervening narrow valleys. Eagle River flows into the Colorado from the east above the Glenwood Canyon and the Roaring Fork joins it at Glenwood Springs from the south. Below Glenwood Springs the river follows through a somewhat wider canyon for about 12 miles entering a broad valley above New Castle and for 30 miles continues through this valley. At Rulison the river enters a canyon again,

through which it continues for 40 miles or nearly to Palisade. There the broad agricultural bottom land known as Grand Valley begins and extends westward beyond the State line.

Physiography

Grand Junction, which marks the lower (western) limit of the drainage considered here, has an elevation of 4,570 feet while the maximum elevation at the headwaters of the drainage is somewhat over 14,000 feet. The upper Colorado River basin, lying between these extremes, includes an extremely rough and rugges area. The valleys have comparatively narrow bottom lands from which the hillsides rise sharply to the tops of the surrounding ridges or cliffs. In the western portion of the basin characteristic plateaus rise nearly a mile above the surrounding valleys. Grand Mesa, Battlement Mesa, the Book Plateau and the White River Plateau are the more important of these. Grand Mesa is the most accessible. It is one of the largest flat-topped mountains in the world, [°] covering nearly 1000 square miles and including hundreds of lakes extensively used for the storage of water used for irrigation.

Geology

Three broad classes of rock formations occur within the drainage: sedimentary, metamorphic, and igneous - chiefly volcanic. Sedimentary rocks belonging to the Silurian, Carboniferous, Jura-Triassic, Cretaceous and Tertiary ages are widely scattered over the lower and intermediate elevations. These include extensive areas of sandstones, limestones and shales lying in nearly horizontal strata except where faulting, folding, or warping in the earth's crust may have changed the original position. The metamorphic rocks include a variety of granites, schists, quartzites, and

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° Water Supply Paper 617, U.S. Geological Survey.

gneisses, located principally in a wide belt along the Continental Divide and other high mountain groups or ranges. Overtopping either sedimentary or metamorphic rocks, eruptive or volcanic rocks, such as trachyte and lava, occur in many places. Grand Mesa, White River Plateau, and a number of the higher mountain formations are covered with rock of this class. It is due to the resistance of the lava-rock capping to erosion that such mesas have retained their plateau-like form. Glacial drift covers extensive areas, mostly at higher elevations. Considerable placer mining has taken place on such an area at the headwaters of the Blue River.

Soil

Throughout the region the character of the soil is dependent upon the existing geological formations. In general, a separate group of soils results from each of the three general classes of rock; i.e., sedimentary, metamorphic and eruptive. The soils derived from the sedimentary formations, including limestones, sandstones and shales, are mostly heavy clays containing varying amounts of sand. This type of soil predominates in the lower and intermediate elevations. Metamorphic granites, schists, gneisses and quartzites give rise to much of the soil found at higher elevations in the form of more or less rock stream, sandy loam and fine sandy or silt loams. These soils in many places are thin and contain a good deal of coarse material but little real soil. The igneous and lava rocks form deep and fertile soils as a rule. The silt and clay loams of the upland areas constitute the principal type in this group. All of the soils with the exception of those derived largely from Mancos shale have an adequate humus content and possess sufficient fertility to support a good vegetative

cover, Within the Mancos-shale soils, alkali is commonly found in quantities sufficient to adversely affect the amount and composition of the plant growth.

The valley bottoms have in many cases been filled with alluvial deposits made up of various mixtures of sand, gravel, clay and organic matter. With irrigation these make excellent agricultural lands.

Climate

A wide variation occurs in the monthly mean minimum and maximum temperatures. At Grand Junction, the lowest point within the drainage, the monthly mean maximum and minimum temperatures vary from: 91° in summer to 36°F. in winter and from 64° to 15°F., respectively; at Breckenridge - elevation 9,530 feet - these vary from 70° to 30°F. and from 36° to 0°F.; at Fraser - elevation 8,670 - from 70° to 26° and from 35° to -5°; at Ashcroft - elevation 9,500 - from 72° to 28° and from 38° to 4°; at Eagle - elevation 6,590 - from 82° to 34° and from 42° to 3°.

The average period between killing frosts varies from 13 days at Fraser to 184 days at Grand Junction. At Breckenridge this period is 35 days, at Ashcroft 65 days, and at Eagle 85 days.

The mean annual precipitation at Grand Junction over a 32-year period is only 8.30 inches. Few records are available for the mountainous portions of the drainage which receive the greatest precipitation. Estimates of the precipitation for such areas based on measured run-off of streams with allowances for losses, transpiration, evaporation and percolation, as given in Water-Supply Paper 617 issued by the United States Geological Survey, give the mean annual precipitation in the upper portion of the basin as varying from 27 to 59 inches. Plate 1 of

this bulletin shows in graphic form precipitation data for the entire upper Colorado River drainage basin and is based upon records up to the year 1929.

Cover

The types of vegetation in this region differ greatly due largely to the varying amounts of precipitation. A cover consisting of semidesert plants, sagebrush, greasewood, shadscale, and saltbush, occurs on the lower portions of the drainage, mostly on the alkali soils derived from the Mancos shale. Sagebrush in nearly pure stands occurs also on dry slopes and adjacent to creek bottoms at intermediate altitudes. Juniper-pinon, oak brush, aspen, Engelmann spruce, Douglas fir, lodgepole pine, and mountain bunch grass make up the remaining principal types. Commercial forest types are found mostly at altitudes between 7500 feet and from 11,500 to 12,000 feet. In places, especially above timberline, relatively large areas of barren rock surface occur. However, the extensive areas of the sagebrush type, scattered throughout practically all ports of the area up to elevations of about 10,000 feet, constitute the most important feature of the region from the standpoint of the vegetative cover. Weeds, grasses, and herbaceous plants occur in varying densities throughout the sagebrush type.

The commercial timber types suffered greatly from fires which occurred in the early days - 30 to 50 years ago. The greater portion of these burned-over areas have become restocked with aspen or, wholly or partially, with the species making up the original timber type. Recent burns are mostly within the sagebrush and oak brush types. During the dry season of 1931 a 1508-acre burn occurred within the oak brush type

on the north slope of Battlement Mesa and many smaller fires were set on private lands largely within the sagebrush type. These fires were especially numerous within the lower portion of the drainage and were set for the purpose of encouraging bluestem and other grasses to replace the sagebrush.

Grazing

Stock raising is one of the principal agricultural activities in the upper basin. The forage available on the rougher lands adjacent to the ranches in the valleys has been utilized by stock ever since the first agricultural settlements were made, in about 1880.

Cattle were for a long time the only class of stock in many portions of the area. Within the past 10 or 12 years, however, there has been a steady increase in the numbers of sheep pastured. Many sheep are grazed on the higher ranges during the summer and later trailed or shipped back to the lower ranges where they are wintered. Excessive grazing, due chiefly to increased numbers of stock, has resulted in serious depletion of the forage throughout much of the lower and intermediate elevations. The grazing homesteads that have been located have reduced the area of public range and have been an important factor in bringing about the present situation. The depletion in forage is becoming serious generally over the area outside of the National Forests and many stockmen no longer have sufficient range for their stock.

Erosion Conditions by Specific Areas

An excellent cross-section of the erosion conditions in the Mancos-shale soils in the lower Grand Valley district is to be observed by following along the Highline Canal of the United States Reclamation Service.

This canal follows the base of the Little Book Cliffs and across an extensive area of semidesert land extending several miles out from the cliffs. The gently sloping ground above the canal has been heavily grazed by sheep for a number of years and has a very sparse cover of greasewood, sagebrush, and shadscale. An idea of the original condition of the cover may be formed by noting the comparatively abundant vegetation present in the limited areas below the canal on which grazing has not occurred, in contrast to the generally depleted cover above the canal. (Figure 68.)

The Reclamation Service has been experiencing considerable difficulty as a result of the enlarging of washes crossed by their canal, also as a result of silting in the canals through erosion. "Big Salt Wash" is typical of a considerable number of these washes. According to Mr. D. L. Henderson, an engineer in the U. S. Reclamation Service, associated with this project for 30 years and intimately acquainted with it, there was but a small wash at this place in 1902-03. He stated that when construction on the project was first started in 1902 this wash could be crossed at almost any place by a team and spring wagon. New vertical walls border the wash, which is from 10 to 15 feet deep and from 100 to 200 feet wide. He also stated that at the time construction was started the vegetative cover on the ground above the canal was much greater than it is today and that a marked decrease in this cover has occurred within the past five to eight years. In fact the surface is largely bare at the present time except for scattered shadscale and very scattered clumps of greasewood. Up until 1908 there was very little change, but the channel then began to enlarge and by 1915 it had reached a depth of approximately

16 feet and a width of 100 feet as shown by the line marked "Original Ground Surface" in Figure 38. By 1928 the wash had been cut down six feet deeper to the new depth shown by the line marked "Present Ground Surface" in Figure 38. Subsequent floods cut the wash an additional two feet in depth to the top of the underlying shale. However, later floods have made deposits above the shale to approximately the "Present Ground Surface." Under the flume-structures, retaining walls and rock-filled wire baskets have been built to protect the sides and bottom of the wash from further cutting. (Figures 65-67.)

Originally the unbridged gully of East Salt Wash could be crossed by teams at a point near the canal. The gully became larger through erosion and a bridge 16 feet long was first constructed at the crossing. This bridge has since been extended until it is now twice its original length. (Figure 67.) This wash in the vicinity of the bridge is now from 40 feet to 200 feet wide and has vertical, actively caving banks 10 feet to 15 feet high. The region above the canal at its crossing of East Salt Wash also has been practically denuded through excessive grazing.

During the early construction of this canal the plans for a ditch provided for a 40-foot flume across a wash. Before this flume was built a flood came down, washing out the area to such an extent that a flume from 200 feet to 300 feet long would have been needed. As a result the location of the ditch was changed.

The irrigation project of the Grand Valley Canal Company was the first in the Grand Valley. Construction of the Grand Valley Canal was started in 1885 and it parallels the Highline Canal at a lower elevation.

Superintendent of Construction, Mike Sullivan, cited several instances indicating an increasing run-off and an enlarging of washes as follows: At the Lewis waste ditch a three-foot by eight-foot siphon or culvert originally carried run-off water under the ditch. In 1896 this siphon was replaced by one having clearance of eight feet by fourteen feet, boxed-in to prevent further cutting of the bottom and sides. This new siphon had a cross-sectional area four and one-half times that of the original structure. Many of the washes are now from three to ten times as wide and deep as they were when the canal was constructed. Mr. Sullivan estimates that the volume of run-off water is now twice what it was 35 years ago. During the past 20 years deepening of the washes has been progressing at an average rate of about one-half foot each year. In places washing has cut through the soil to the shale so that in certain instances the piling which supports the flumes rests on the surface of the ground in the bottom of the washes.

At the Pamona Wash, which Mr. Sullivan says could be crossed practically any place 35 years ago by a team, there is now a gully 12 to 16 feet deep and 40 to 200 feet wide. This wash from 1883 to 1896, according to Mr. Sullivan, had only a three-foot by eight-foot culvert and it carried all flood water under the ditch. In 1896 a 16-foot length of flume four-feet by eighteen-feet was constructed across the wash which had developed as a result of increased run-off. By 1930 a flume 128 feet long was required to carry the canal across the wash. This wash is now ly feet below the bottom of the flume and cut down to the shale. Flood waters usually run five or six feet deep and continue to cut into the sides of the gully where no protection, such as rip rap, has been provided.

The Holland Wash (No. 4 Flume) originally had a three-foot by eight-foot culvert under the ditch for the purpose of carrying off flood waters. That culvert served until about 1911 when a 16-foot length of flume was built. It was adequate for a period of eight years after which it had to be lengthened. Now a flume 48 feet long crosses the wash at this place and the sides of the gully under the flume are boxed-in to protect them against further widening. Above and below the flume the wash is now 12 to 16 feet deep and 50 to 150 feet wide with vertical banks which are continually caving.

Conditions on each of 22 other washes along this irrigation canal are similar to those described above for the Holland wash. The lower portions of many of these washes have in some instances cut out to a depth of 20 to 30 feet or until solid shale was reached and widths will range from 100 to 250 feet. (Figure 39.)

On the lower portion of the East Salt Creek drainage, between the Highline Canal and the canyon above, there is a flat on which semidesert conditions prevail. The greasewood-shadscale type which covers most of this lower portion is badly overgrazed and depleted. In the canyon above there is a cover of sagebrush in which herbaceous vegetation is almost entirely lacking. The upper, or canyon, portion is in the Mesa Verde and Wasatach formations; the lower portion is within the Mancos shale. The gully in which the stream bed is located has been actively cutting wider and deeper in late years. For example, cottonwood trees, started at what apparently was formerly high-water level, are now on benches two to eight feet above the bottom of the gully through which a small stream flows intermittently. Near the head of the canyon the hillsides, covered with

oakbrush, rise more abruptly. In that locality there are some badly trampled and overgrazed spots where evidence of excessive run-off accompanied by sheet and gully erosion exist but, as a general rule, the oak brush type there is in good shape. The bottom of the canyon has a deep, actively cutting gully extending through its entire length. The distribution of the cattle grazing in this gulch seems to be uneven with heaviest use in the bottom. The most serious erosion is occurring on the heavily used areas. The upper slopes show much less serious erosion than is occurring in and near the bottom.

On the Big Salt Wash drainage trees also are growing on benches at elevations several feet above the present water channel. In such cases the trees, now 30 years or more old, started as seedlings in the moist dirt near the water's edge and subsequent deepening of the gully has left them on benches above the stream channel. (Figures 72-73.)

About 12 miles north of Fruita, immediately below the steeper slopes of the Little Book Cliffs, on what is known as the Gar-Mesa ranch, a small reservoir project was started in 1908. The ditch began at the mouth of a rough canyon and, about one-half mile above the reservoir, which covered 40 to 80 acres, passed through a settling basin dammed by a 20-foot embankment. The only available water was flood water which always carried considerable sediment and so much sediment was brought down that the settling basin was soon filled. For a time a steam shovel was used to remove it and two large piles of detritus were dumped below the basin. (Figure 74.) Even with the settling basin in use a great deal of sediment was carried on into the

reservoir, rapidly filling it. The reservoir dam was raised from time to time and as late as 1915 work was still being done on it. The reservoir now appears to be about one-half full of sediment and its usefulness has been largely destroyed. (Figure 75.) The expense of cleaning ditches and raising the dam was so great in this case that the project has virtually been abandoned for a number of years.

Between this reservoir and the Highline Canal there is a considerable area of land which has been under fence for several years and protected from the excessive grazing which the surrounding area has undergone during the same period. Within this protected area one can obtain an excellent idea of the nature of the cover which originally covered the entire bottom land. Within the enclosure is a good stand of tall greasewood and shadscale having a fairly good undercover of grass and other herbaceous plants. (Figures 70-71.) Especially noticeable is the amount of litter in the form of twigs, leaves, etc. on the ground surface. Indications of considerable high water exist within this fenced area but only minor sheet and gully erosion have occurred. In contrast to these conditions most of the greasewood has disappeared from outside the enclosure. No grasses are found and no litter occurs on the ground. In fact the ground surface outside is largely bare except for scattered greasewood, shadscale, and saltbush.

Plateau Creek is the first important tributary of the Colorado River above Grand Junction. It heads on the north slope of Elk Mountain, and in the valley between Grand and Battlement Mesas and flows into the Colorado several miles above Palisade. This drainage is located almost entirely within the Wasatch formation except for an area near the upper

limits where the Green River formation appears. At the mouth of this creek the stream was very low but the water was turbid at the time of the examination with silt previously deposited along the channel and at the outlets of sidestreams. Eight miles above the mouth of the creek the water was very clear. Very little cutting was taking place along the main stream bottom since the boulders in the channel largely prevented this. Side streams have washed in considerable detritus from steep semibarren slopes which have also been heavily grazed and trampled but due to the fall of these streams the speed of the current is sufficient to keep most of the sediment in motion. Heavy run-off is indicated on many of the lower slopes. This condition continues until about seven miles above Collbran. Throughout the intermediate and upper portions of the valley landslips, in the shale and limestone formations, are common. Considerable sediment is carried in the run-off from the area in which landslips have recently occurred.

The juniper-pinon type is rather seriously eroded where grazed heavily, trampled, or burned over. The oak brush type shows little erosion except where burned over or excessively grazed and trampled. About seven miles above Collbran the road turns into the Buzzard Creek Valley, one of the main tributaries of Plateau Creek. Buzzard Creek is sluggish with some bank cutting and silting in evidence. Near the National Forest boundary the hillsides are covered by sagebrush. The herbaceous vegetative cover within the sagebrush type has been seriously depleted and heavy sheet erosion is in progress on most of the slopes, as indicated by the occurrence of brush on hummocks and by accumulations of soil back of chips, exposed roots, and brush. The natural drainage

depressions are beginning to show many gullies, of small size but steadily widening and deepening. On rather extensive areas of the sagebrush type the soil has a thin, worn appearance which indentifies it as eroding to a considerable extent. The most serious conditions exist on areas where grazing is uncontrolled and where such aggravated conditions as badly depleted cover are contributing to heavy erosion following rains. Within the National Forest boundaries some sheet erosion, as well as channel cutting and gullying, is occurring, a condition which, while not serious, yet needs possibly some corrective measures such as elimination of too early spring use to prevent the development of excessive erosion. Throughout the sagebrush type there is a deficiency of herbaceous vegetation and possibly sagebrush has come in on certain areas as a result of overgrazing.

Buzzard Creek, above Owens Creek, has a cover of Artemisia cana while lower down on the drainage, black sage, Artemisia tridentata, prevails. In this area there are also some thin-appearing spots but they are not of serious proportions. Above Buzzard Creek the Muddy Creek drainage has rather large parks of big mountain bunch grass with aspen and Engelmann spruce growing on the higher slopes. In general there is little erosion within the bunch grass or timber types.

The Alkali Creek drainage is also largely covered with the sagebrush and oak brush types. At the headwaters of this basin there are thin spots in the soil and a generally depleted herbaceous undercover as a result of excessive grazing, and some erosion is occurring.

It is noticeable in going from the valleys transversely to the higher elevations that evidence of erosion decreases. The top of Grand

Mesa - capped by lava - shows very little erosion. Silting in the lakes on the Mesa is not appreciable and the rocky lake bottoms show very little sediment. The Engelmann spruce type shows practically no erosion and the aspen type is for the most part in good condition except for some small flats and concentration areas which show undesirably heavy grazing use with minor gullying and sheet erosion. The oak brush type is generally in good shape. Juniper-pinon areas and the sagebrush type are clearly showing heavy erosion but to a lesser extent than the semidesert Mancos shale areas of the lower Grand Valley.

The diversion dam of the Grand Valley project of the U. S. Reclamation Service is located a short distance above the mouth of Plateau Creek. This dam has six headgates which can be opened separately so as to influence the location of the channel. After the irrigating season, silt deposits which have accumulated above the dam are washed downstream by causing the channel to wash away the mud. This accumulation is very appreciable and the silt shows up very conspicuously when the level of the water above the dam is lowered. (Figure 40.)

The Colorado River between Palisade and Debeque is located in a deep canyon cut through the Wasatch formation for a distance of 20 miles. Above and below this canyon, the west side of the valley is bordered by a line of steep, barren and badly eroding cliffs known as the Little Book Cliffs. (Figure 41.) Within the canyon section some of the side drainages contribute large amounts of sediment to the river. Following rains deposits of mud and sand carried into the Colorado from side drainages are frequently to be seen along the channel. (Figure 42.)

Between Debeque and Rifle there is a badly depleted vegetative

cover - result of grazing - within the sagebrush type bordering the river bottom; and excessive sheet and gully erosion are taking place. Large quantities of course detritus are also washed from the cliffs and deposited on the flat at the foot of the cliffs while the finer sediment goes on into the river.

Government Creek flows southeast into Rifle Creek just before the latter joins the Colorado River at Rifle. Government Creek valley lies mostly within the Wasatch formation. Its cover is largely sagebrush in the bottoms with juniper-pinon and oak brush on the hillsides. The narrow valley bottom, through which a small, intermittent stream flows, is filled with a deep alluvial soil containing a large proportion of clay. This entire valley, about 20 miles long, is used largely for pasture. Some of the lands are owned by sheepmen who use them for lambing grounds and the vegetative cover on much of the bottom land has been seriously depleted as a result of overgrazing. The Grand Hogback, in which the horizontal strata of the Cretaceous and Tertiary formations have been pushed up and practically rests on edge, forms the east side of the valley. The cover on the Hogback is largely juniper-pinon, oak brush and sagebrush with numerous small areas of nearly barren shales resembling badlands. The run-off is excessive on the eastern side of the valley. A good cover of oak brush on the west side of the valley seems to be effectively holding the soil against erosion except along the foot of the slopes where excessive grazing has occurred and erosion is active. Some relatively small landslips have occurred on the upper slopes on the west side.

Each little gulch at the head of the drainage has a deep, active

gully extending downstream from the divide. These gullies, uniting, form a main gully which increases in depth and width and continues down the valley for nearly 20 miles. This valley shows the greatest depletion in vegetative cover of any area in this locality, and serious sheet and gully erosion are occurring. Cottonwood trees are growing on terraces which are from four feet to eight feet above the present channel of the stream, indicating an appreciable deepening of the wash or gully within the past two or three decades, or since the trees became established. In places there are in the gully three or more such terraces rising above and parallel to the creek at intervals of a few feet, each of comparatively recent origin. Serious erosion has increased greatly within recent years and seems to be constantly becoming worse as the vegetative cover is further depleted.

In 1930, two floods came down Government Creek each of which took out a bridge. One man was drowned and the cost of replacing the bridges was about $60,000.00. The town of Rifle is located at the mouth of the Rifle Creek Canyon into which Government Creek has its outlet and is almost directly in the path of any floods coming down this drainage. The channel of Government Creek at a point just above the mouth shows that floods have in late years done an excessive amount of cutting and enlarging of gullies. (Figure 43.)

Rifle Creek drains a large valley east of the Grand Hogback. Here the sedimentary strata, ordinarily horizontal in position, have also been pushed up on edge. West Rifle Creek valley is largely within a Mancos shale formation with the Dakota sandstones and Jura-Triassic formations appearing to the east. The Hogback, rising to a height of

800 to 1000 feet, is made up of the Mesa Verde and Wasatch formations and is covered by the juniper-pinon type. Sagebrush makes up the type in the bottoms along West Rifle Creek.

W. L. Clark took up his homestead several miles above the mouth of this creek in 1887. He says that the flats which now support a luxuriant growth of sagebrush, were covered at the time he settled there by a good stand of bluestem and that in the earlier days he mowed hay from the flats which he sold for use at the livery barn in Rifle. (Figure 44.) Mr. Clark pointed out the location of the original headgate of the ditch through which he takes water from West Rifle Creek. (Figure 45.) The creek at this point now flows in the bottom of a deep, vertical-walled gully, several feet below the elevations of the ditch which has been extended upstream to a point where an intake could be located "on grade." The original ditch and headgate served for 15 or 20 years, when the gully first started to form. It then became necessary to extend the ditch upstream to get water, and further extensions were made later - finally by means of a flume -as the gully grew larger and deeper. (Figure 46.) A gradually depleted grass cover resulting from excessive grazing has in the opinion of Mr. Clark resulted in greater run-off, followed by excessive gullying. Mr. Clark also states that the flow of the creek is now two or three times the size it was when he came there. He accounts for this by the fact that, due to irrigation higher up, more water is held in the ground through which it percolates, seeping slowly back into the creek. It is more likely, however, that the increase is due to the accumulated soil being cut down to the

shale bottom exposing the underflow of water which was always there. In the lower valley a small depression which drains flood water from the surrounding slopes and which originally could be crossed by a team almost any place is now impassable because of gullying. Mr. Clark says that most of the active gullying has taken place within the past 10 to 20 years and it seems to be continuing now as fast as at any previous time. At one place below his ranch where the water course was crossed by a wagon road for many years, there is now a gully 50 feet deep (Figure 47.) Sagebrush plants eight feet high and showing 26 annual rings of growth in the larger stems are growing in the old ruts of the existing remnants of this road, indicating that it has been impassable for at least a quarter century. (This is apparent in the center of the photograph designated Figure 47.) The Mancos shale soil in this valley seems to erode more deeply and to cave more actively than the clay derived from the Wasatch formation found in the valley just over the Grand Hogback where the grazing use is severe and where the run-off is equally great.

A Mancos shale soil extends across Rifle Creek valley into the West Elk Creek drainage to the east. Throughout that area there is a seriously depleted herbaceous undercover beneath the sagebrush and excessive sheet and gully erosion are in evidence everywhere.

Elk Creek which empties into the Colorado River at New Castle shows excessive erosion in the lower drainage where the greatest depletion in vegetative cover is also evident. Excessively high water occurred in 1929 and again in 1930 which did considerable bank cutting, leaving a broad shallow river channel. The higher side slopes of the

lower Elk Creek valley within the oak brush type also show some minor land slips, the detritus from which tends to increase the sediment in the water coming from these slopes.

Within the White River National Forest boundary, several miles above New Castle, there is a good cover consisting of aspen and oak brush types supporting a good undercover of weeds, grasses and litter. These types indicate that little erosion is taking place. A small storage reservoir on a creek inside the Forest supplied entirely from flood run-off has been used 15 years and its empty basin showed no evidence of silting. The upper part of Elk Creek and the White River Plateau, which are largely within the aspen, grassland and Engelmann spruce types, show no appreciable erosion under the existing excellent cover conditions.

The Roaring Fork joins the Colorado River at Glenwood Springs. The mouth of this stream shows very little indication of erosion along its channel. The channel was also examined at several crossings between the mouth of the creek and Aspen and generally it was found to have an excellent appearance. Its rapid flow apparently carries all sediment on downstream. Several localities show excessive erosion on steep slopes bordering the valley, especially where the vegetative cover is limited, a characteristic situation in much of the juniper-pinon type. (Figure 48.)

Between Carbondale and Basalt the Roaring Fork Valley shows little erosion. However, about three miles above Basalt a flood occurred two years ago, resulting from run-off from a steep, rocky hillside where the cover type consisted of juniper and pinon and where

serious overgrazing had occurred. It nearly buried a set of farm buildings with mud, rock and debris and as a result the owner had to rebuild across the river.

The Roaring Fork Valley in the vicinity of Aspen and above to the Continental Divide is in fine condition from the standpoint of cover and very little erosion is taking place. There are, however, some places in the vicinity of Aspen where water from ditches has been allowed to escape on steep slopes resulting in some bad washes.

Crystal River, a tributary of Roaring Fork from the south, heads in the high mountains above Marble. At the time of the examination it was carrying considerable fine sediment near its outlet. The lower part of Crystal River flows through farm land and that part of the drainage is not eroding to any great extent. The upper portion of the river is within a narrow canyon with steep, rocky hillsides on each side. The naturally rocky surface and excessive slopes have in places resulted in large quantities of rock and gravel, along with finer material, being washed into the river channel. Some of these areas have not been grazed and the erosion which is taking place is a natural condition unaffected by the activities of man. There are some places, however, where grazing by sheep has depleted the cover on naturally steep, rocky surfaces easily susceptible of erosion and on those areas sheet and gully erosion are excessive. (Figures 49-51.) In the canyon of Crystal River nearly every watercourse is choked at the lower end by debris washed down from above. The highway on one side of the stream and the railway on the other have often been covered with rock and mud following rains. Avalanche Creek

has an excessive gradient and has at some time in the past filled the river channel for one-half mile below its outlet with boulders and gravel.

Vegetation along the Crystal River valley bottom is sparse, due to the repeated driving of from 8,000 to 10,000 sheep to and from summer range along this route and at the time of the examination a very dry season had added to the barren appearance of the ground. The higher slopes in this drainage are not grazed. At Redstone, Coal Creek has carried down considerable detritus. The lower portion of the Thompson Creek watershed also shows indications of considerable erosion in the form of mud deposits along the channel.

About a mile below Marble a mud flow (Figure 52) has come down from an area of barren Cretaceous shale cliffs and ledges located at a considerable elevation above the town. After every rain there is more or less new material carried down and the town, for its own protection, has constructed a barrier to divert this flow to a point down stream. In 1930 an especially heavy mud flow covered the railway and highway with several feet of mud and rock. This erosion also is due to conditions which are natural and unavoidable. A considerable portion of the upper Crystal River is within Cretaceous formations corresponding to the Mancos shale and Mesa Verde formations from which easily eroded soils are formed.

There is an excellent vegetative cover on the upper portion of the Crystal River drainage with no apprecible erosion. In flood seasons the lower part of the river carries a rather large amount of silt and its channel shows mud and silt deposits in many places. The mud flow

at Marble and numerous side drainages lower down all contribute sediment largely as a result of prevailing natural conditions. In addition to this natural erosion, however, there is a limited amount of erosion which seems to be especially active where the cover has been depleted through heavy grazing use. This is illustrated by conditions near Hot Springs station and at the Thomas sheep ranch where the results of heavy grazing are evident and where accelerated erosion is occurring.

Sopris Creek, a tributary of Roaring Fork, is clear and has a clean channel. Snowmass Creek, another tributary, also shows little results of erosion. These creeks, Brush Creek, and the lower part of Capitol Creek, although in a clay soil derived from Cretaceous formations, have an adequate vegetative cover and are in good condition, except for a few heavily grazed spots showing some sheet and minor gully erosion.

In the Fryingpan River drainage, tributary to the Roaring Fork Valley from the east, a limited amount of erosion is taking place below Ruedi. Heavy grazing in that locality has depleted the cover within the juniper-pinon type on steep and rocky slopes. From such areas considerable material has been washed into the river and some severe gullying has taken place. The red soils in the vicinity of the Sloss ranch show some excessive sheet erosion. The vegetative cover has been badly depleted and heavy rains invariably bring down quantities of sediment which fill irrigation ditches and damage fields.

The vegetative cover in the upper basin of the Fryingpan River consists of sagebrush on dry benches and on the lower slopes with brush land, aspen, lodgepole pine, and Engelmann spruce on the higher slopes.

There is a good undercover of grasses and herbaceous plants or litter within these types and no appreciable erosion is occurring.

Eagle River is contributing considerable quantities of sediment to the Colorado, principally from the lower 30 miles of its drainage, extending from the vicinity of Wolcott to its outlet. The man in charge of the diversion dam of the Shoshone power plant says that high water coming from the Eagle River is colored red while that from the upper Colorado is yellow. Around the upper edge of the back water above the Shoshone dam there is evidence of considerable silting. The lower part of the Eagle River drainage is within the Carboniferous formations. The vegetative cover includes sagebrush in the bottoms and on lower slopes with juniper-pinon and oak brush on the upper slopes. Grazing has been very heavy, especially within the sagebrush and juniper-pinon types, and much of the ground surface is bare. North of the river is a large area of rock surface and soil devoid of vegetation comprised principally of gypsum hills (Figure 53) within which erosion is active. The lower part of the Gypsum Creek drainage has an easily eroded clay soil which furnishes considerable sediment. The lower part of the Brush Creek watershed also includes some gypsum hills which leave rather barren surfaces and show considerable erosion. The hills north of Eagle River in the vicinity of Eagle and Wolcott are largely clay soil with a sagebrush cover, partly within a Mancos shale area on which sheet and gully erosion are excessive. Alkali Creek and its principal tributary, Muddy Creek, flowing into the Colorado from the north drain part of the area between the Eagle and Colorado Rivers. Upstream from Wolcott evidence of erosion becomes much less noticeable; the stream channel

is clean, the water is clear, the hills are well covered with vegetation, largely aspen and coniferous timber types, and very little erosion is occurring from any of the upper drainage.

The Colorado River drainage for a considerable distance above the mouth of the Eagle River is largely within the sagebrush and juniper-pinon types, both of which are heavily grazed. It has a badly depleted cover and is undergoing excessive erosion in many places. This is especially true of the areas between McCoy station and State Bridge where erosion conditions are very bad. In the lower valley of Egeria Creek the chief tributary of Rock Creek which flows into the Colorado from the north in the vicinity of McCoy several small ranches are located on agricultural flats. Geological formations of the Jura-Triassic age prevail and gradients are rather steep. A deep, vertical-walled, actively eroding gully of recent origin has been carved to a depth of from 10 to 15 feet and to a width of from 30 to 100 feet through this farming land. In fact, the red soils throughout the lower part of the valley are eroding excessively. The upper part of the valley has a much better vegetative cover and only moderate sheet and gully erosion are occurring there.

The Colorado River channel shows numerous mud deposits at intervals as far upstream as Kremmling and below that point, even at low stages, the water is ordinarily slightly turbid. Between State Bridge and the west end of Gore Canyon serious gullying is taking place on both sides of the river on lands largely privately owned though some public lands, principally unreserved public domain, are scattered throughout the area. Heavy grazing is the general practice over the entire region and a seriously depleted herbaceous undercover exists throughout the sagebrush

and juniper-pinon types. Sheep outfits have, within recent years, been making heavy use of portions of this region where heretofore only limited numbers of cattle were ranged. As a result the vegetative cover is being rapidly depleted. The lower Sheephorn Creek drainage and practically all of the area outside the National Forest boundaries in this region show serious sheet and gully erosion.

Above Gore Canyon three drainages are heavy contributors of silt to the Colorado as follows: Muddy Creek and Troublesome Creek from the north and Blue River from the south. Muddy Creek empties into the Colorado at Kremmling. The stream is about 30 miles long and drains the northwestern portion of Middle Park. It winds through a broad valley bottom of clay soils derived from Cretaceous and Tertiary formations. The vegetative cover is made up of sagebrush, rabbit brush, and such grasses as grama, wheat grass, and bluestem. Heavy grazing has been carried on there for years until the cover has become seriously depleted. As a result serious sheet and gully erosion are in evidence over practically the entire area. The stream at low water is quite muddy with sediment picked up from the mud deposits along the channel. The volume of run-off water is excessive over the entire basin and each rain causes high water carrying considerable mud. This valley is probably the heaviest contributor of silt of any of the upper tributaries of the Colorado River. This area of clayhills around the Muddy Creek valley has been eroding badly for a long time and apparently the process is more active than at any time within the past two or three decades. (Figure 54.)

Troublesome Creek drainage includes a considerable area of

clay soils which support only a sparse and depleted vegetative cover similar to that on Muddy Creek. It also shows excessive erosion. (Figures 55-56.) The lower part of this drainage is contributing most of the sediment. The upper portion has a better vegetative cover and does not appear to be eroding badly.

Blue River drains the southwestern part of Middle Park. This river heads near the crest of the Continental Divide and its upper portion contains gravel beds which have been placer-mined extensively at intervals since 1860. Some work is still in progress. The vegetation in the valley and on the lower slopes consists primarily of sagebrush and rabbit brush, with limited amounts of grama grass, bluestem, and weeds; while on the upper slopes it consists principally of aspen, lodgepole pine, or Engelmann spruce. In the lower part of the valley the soil is composed of clay of the Cretaceous and Tertiary formations. Grazing has been excessive on the lower 15 miles of the valley and the cover has become badly depleted. Excessive sheet and gully erosion are taking place throughout this part of the valley. Gullies in all stages of development exist and the road has repeatedly been washed full of detritus from the poorly protected slopes above it. These conditions are most conspicuous near the mouth of the creek. (Figure 57.) The intermediate part of the valley is grazed by cattle owned locally. That part of the valley is not used to excess for grazing and erosion is unimportant. Mud deposits appear in the stream channel below Slate Creek - which joins the Blue River on the west a little less than halfway from the outlet to the source - and tailings from mining operations on Ten Mile Creek near the Continental Divide and placer mining on the

main river have clouded the upper river to some extent. The principal mine now operating - the Climax, at the head of Ten Mile Creek - is trying, fairly successfully, to keep the tailings out of the stream. Its settling basin contains a large mass of sediment (Figure 58), a small part of which gets into the stream in spite of efforts to keep it out. The upper valley slopes are well protected, chiefly by timber or grasses, and little erosion is taking place there.

Along the Colorado River at Kremmling considerable bank cutting is in evidence and more or less actively eroding surfaces exist on both sides of the valley, between Kremmling and Parshall. Above Parshall a noticeable decrease in indications of erosion is evident and the general condition of the river channel is excellent. The vegetative cover is adequate to provide protection from erosion and does not show indications of excessive use. Heavy stands of lodgepole pine and Engelmann spruce at the extreme headwaters effectively protect the very steep slopes against any appreciable erosion.

Robert Follansbee in Water-Supply Paper 617 of the United States Geological Survey states that the quantity of sediment in the upper Colorado River and its tributaries is small compared with that in the lower basin. The amount carried in suspension has been estimated at 167 acre-feet annually at Kremmling, 950 acre-feet annually at Palisade and 8,175 acre-feet annually at the Dewey reservoir site just below the mouth of the Dolores River in Utah.

Mr. Follansbee also says, "Upper Colorado River and its principal tributaries are not subject to floods in the commonly understood sense of the term. The high water is due to the melting of mountain snow and

occurs with great regularity each year.....' A study of the table shows that the average date of maximum discharge is latest at the station furtherest upstream and is only a few days earlier at lower points as far downstream as Palisade, but for the Gunnison River it is about 10 days earlier. This difference in dates is due to the difference in mean altitude of the drainage basins above each point, the snow melting earlier at the lower altitudes." He states that within the past 20 years there have been four periods of heavy rains as follows: September 3 to 6, 1909; October 4 to 6, 1911; June 3 to 7 and 14 to 21, 1921.

The highest known water stage in the Colorado River was reached in 1884. Weather Bureau records show that a high-water stage occurred at Fruita, the flow of which was determined from computations by Mr. Follansbee to have amounted to 125,000 second-feet. The few bridges across the Colorado and Roaring Fork and several bridges along the lower Gunnison were all destroyed by the flood.°

The following statements summarize the situation in a general way; not only within the upper part of the Colorado River drainage but also equally well for the conditions on the other major tributary streams in Colorado.

Active sheet and gully erosionin practically all their various stages are occurring in many localities throughout the region. In nearly all cases of excessive erosion there is evidence of a material increase in the rate of cutting within recent years. Examples of increased or accelerated erosion include the rapid enlargement of the washes which cross the irrigation canals in the vicinity of Grand Junction, the

°Water Supply Paper 617.

existence of large impassible gullies at places where roads formerly crossed depressions, and the numerous instances where roads, railroad tracks or fields have been or are filled with mud or debris.

On soils of the same type both sheet and gully erosion seem to vary in direct ratio to the density of the vegetative cover. This is illustrated by conditions above the Highline Canal near Grand Junction where the soil supports only a sparse cover of shadscale, greasewood, and saltbush and shows much more active erosion than a similar area in the same general vicinity which has been enclosed by a fence and on which the vegetation has not been depleted by excessive grazing. The latter area, which shows very little erosion, supports a much better stand of shrubs in its original, undisturbed condition, including an undercover of grasses, weeds and litter on the ground.

It is apparent that in certain places there is, even under natural conditions, an insufficient vegetative cover to hold the soil in place and on such areas erosion is invariably excessive. Some of the shales within the Mancos and Wasatch formations illustrate this condition.

Excessive run-off accompanied by considerable gullying have occurred on extremely steep slopes even where a good natural cover is present and is undisturbed by grazing or activities of man. The degree of erosion is greatly increased where very steep slopes, such as the Little Book Cliffs, aredevoid of vegetation.

Within the upper Colorado River watershed the most actively eroding areas will be found where soils are derived from formations of the Cretaceous and Tertiary ages. These formations are made up

largely of shales which give rise to easily eroded clay soils. In places the Jura-Triassic formations have given rise to readily erosible sandy soils but such areas are relatively small in the upper Colorado River drainage. Soils formed from the Cretaceous and Tertiary shales and other rocks appear on the Colorado River as far upstream as the vicinity of Kremmling. Above this area of sedimentary soils there is very little sediment being washed into the river.

Computations of sediment carried in suspension by the Colorado River show the following amounts per annum:

Point of observation	Amount of sediment acre-feet	Total area of drainage basin above point of observation	Acre feet of sediment per 1000 acres of drainage area
Kremmling	167°	2360	70.8
Palisade	950	8790	108.0
Grand Junction	2150	16930°°	127.0

° Below the outlets of Muddy Creek and Blue River.
°°Including the Gunnison River valley.

These points of observation have drainage basins above them of approximately 2,360 square miles, 8,790 square miles, and 16,930 square miles respectively. The tendency for the amount of sediment per unit of drainage area to increase more or less in ratio with the distance from the source of the stream is conspicuous. Even with a very liberal allowance for the bed load of silt in this upper drainage the amount of sediment per square mile of drainage area is much lower than it is at the Hoover Dam site - above which there is a drainage basin of approximately

167,000 square miles - with an estimated total suspended and bed load of sediment amounting to 137,000 acre-feet annually or 820 acre-feet per 1000 square miles.

Roughly classifying the area of the upper Colorado River drainage, within Colorado only, into three broad classes as to degree of erosion, the percentages arrived at are as follows:

Areas of heavy erosion	33 percent
Areas of moderate erosion	27 percent
Areas of little to no erosion	40 percent
Total	100 percent

These figures are merely very rough approximations based on the extensive examination of the area and may be materially changed as a result of a more thorough classification.

Longer and larger bridges are being constructed across what formerly were small unimportant water channels and in places highways have required the construction of expensive retaining walls to prevent destruction of the road by further widening of flood channels. These are the most evident effects of the increasing run-off and accelerated erosion although in certain instances farm lands or buildings are being seriously damaged by floods which are apparently occurring with increasing frequency in places which for many years had not been troubled in any way by flood waters.

Erosion and especially active gullying have been growing more noticeable, and excessive run-off has been doing such material damage within resent years that the attention of local residents, especially stockmen who have long been familiar with local conditions, is being attracted to the increasing seriousness of the existing conditions.

They realize that excessive erosion is occurring and often comment on it. There are various opinions as to the cause of the increased erosion and there is a growing tendency on the part of many individuals to attribute it to the destruction or depletion of the original vegetative cover, largely through grazing and trampling.

There must be certain definite causes responsible for the present increased run-off with the accompanying acceleration in erosion and the situation would seem to justify further intensive study to definitely determine the causes back of it all and to work out practical and effective remedial measures.

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